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THE MARINE GEOLOGY OF THE INNER SCOTIAN SHELF OFF THE SOUTH SHORE, NOVA SCOTIA

David J.W. Piper
P.J. Mudie
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CONTENTS

- 1 Abstract/Résumé
- 1 Summary/Sommaire
- 3 Introduction
  - 3 Purpose
  - 3 General geology setting
  - 4 Responsibilities of authors
  - 4 Acknowledgements
- 5 Methods
- 5 Physiography
- 7 Bedrock geology
- 12 Morphology of the bedrock surface
  - 12 Description
  - 14 Interpretation
- 15 Late Wisconsinan and Early Holocene sedimentation
  - 15 Glacial stratigraphy: existing concepts
  - 15 Acoustic stratigraphy
    - 15 Introduction
    - 15 South of Cross Island
    - 17 LaHave estuary – Lunenburg Bay – outer Mahone Bay
    - 18 Mahone Bay
    - 18 St. Margaret's Bay
    - 18 Port Mouton – Liverpool Bay area
    - 19 Summary
  - 22 Distribution and character of till
  - 23 Piston core sediments
    - 23 Lithostratigraphy
    - 24 Sedimentology
  - 26 Piston core biostratigraphy
    - 26 Introduction
    - 26 Core 74-1
    - 29 Core 77-12
    - 32 Core 76-02
    - 32 Core 77-16
    - 34 Core 78-100
    - 35 Core 77-14
    - 35 Core 77-15
    - 36 Core 78-118
    - 36 Core 78-112
  - 37 Stratigraphic summary
  - 37 Relative sea level changes
    - 37 Introduction
    - 37 New data
  - 39 Late Glacial geological history of the South Shore
- 42 Surficial Sediment
  - 42 Distribution
  - 42 Granulometric analysis
    - 42 Sable Island Sand and Gravel
    - 44 LaHave Clay
  - 44 Sedimentary structures
  - 45 Gravel petrology
  - 46 Mineralogy of heavy minerals
  - 51 Clay mineralogy
  - 51 Surface textures of sands
  - 51 Evolution of contemporary sediment

52 The coastline
52 Introduction
52 Bedrock coast
52 Till cliffs
52 Beaches
54 Marsh and tidal flat
54 Holocene sediment budget
54 Introduction
54 Sources of sediment
54 Sediment budget model
55 Contemporary rates of sediment supply
55 Export of clay from coastal zone
56 Thickness of contemporary sediment
56 Rates of sedimentation
56 Total Holocene sediment supply
57 Interpretation of Holocene sediment budgets
58 Geomorphic Evolution
61 Conclusions
61 Bedrock distribution
62 Late Pleistocene glacial history and sediment distribution
62 Later Holocene and contemporary processes
62 References

Tables

27 1. ^{14}C dates from marine samples
28 2. Relative abundance of pollen and spores in core samples
30 3. Relative abundance of dinoflagellate cysts and acritarchs in core samples
46 4. Heavy minerals
48 5. Clay mineralogy
49 6. Rates of cliff retreat
55 7. Nearshore sediment budget

Figures

4 1. Map of study area
in pocket 2. Location of seismic reflection profiles and bottom samples.
in pocket 3. Bathymetry of the South Shore
in pocket 4. Location of the more detailed figures
6 5. Detailed bathymetry of area south of Cross Island.
7 6. Detailed bathymetry of area in southwest Mahone Bay.
8 7. Detailed bathymetry of Lunenburg Bay
9 8. Hypsometric diagrams
9 9. Distribution of steep sided, narrow channels
in pocket 10. Bedrock geology of the South Shore
10 11. Total magnetic field, western Mahone Bay
10 12. Magnetic profiles, northeast basin of Mahone Bay
10 13. Magnetic profiles, Lunenburg region
11 14. Total magnetic field, Port Hebert region
11 15. Magnetometer profiles across a possible dyke east of Big Tancook Island
in pocket 16. Generalized morphology of bedrock surface
12 17. Seismic reflection profile, LaHave estuary
12 18. Seismic reflection profile south of Cross Island
13 19. Profiles in Port Mouton area
14 20. Seismic reflection profile from Bull Rock Channel

16 21. Seismic reflection profiles and cores south of LaHave estuary-Mahone Bay
17 22. Depth to bedrock south of LaHave estuary-Mahone Bay
18 23. Seismic reflection profile through core sites 78-109 to 78-112
18 24. Seismic reflection profile from Bull Rock Channel
19 25. Distribution of acoustic unit south of LaHave estuary-Mahone Bay
20 26. Correlation of selected long piston cores
21 27. Location of piston cores
21 28. Seismic reflection profile, Bull Rock Channel
22 29. Distribution of early and late tills south of LaHave estuary-Mahone Bay
23 30. Acoustic units, Port Mouton area
24 31. Distribution of till, South Shore
25 32. Petrology of gravel samples, Lunenburg Bay
25 33. Petrology of tills and gravel samples, Port Hebert region
25 34. Grain size analyses from sediment facies 2
26 35. Lithostratigraphy of core 78-112
27 36. X-radiographs of laminae from cores 78-118 and 78-112.
29 37. Grain size analyses from sediment facies 3 and 4
29 38. Lithologic data from core 74-1
31 39. Lithostratigraphy and palynomorph abundance in core 74-1
32 40. Lithologic data from core 77-112
33 41. Lithostratigraphy and palynomorph abundances in core 77-12
34 42. Lithostratigraphy in cores 77-15 and 78-100
35 43. Bathymetry of area southeast of Cross Island
38 44. New data on sea level change
38 45. Three hypotheses for relative sea level changes
40 46. Schematic model of deposition of acoustic stratigraphic units
41 47. Location of cores and seismic reflection profiles
in pocket 48. Surficial sediment distribution, South Shore
43 49. Modal grain size of surficial sands and gravelly sands
44 50. Selected grain size analyses from Sable Island Sand and Gravel
44 51. Grain size distribution in surficial gravels, Cadden Bay
45 52. Plot of skewness against sorting from the Sable Island Sand and Gravel
45 53. Grain size distribution in acoustic unit d
46 54. Lithologic composition of gravel samples from tills and beaches, Lunenburg Bay
47 55. Heavy mineral assemblages of Sable Island Sand and Gravel
48 56. Plot of opaque minerals against gravel type for Lunenburg Bay
49 57. Heavy minerals, Green Bay
49 58. Plot of opaque minerals against mean grain size for Green Bay and Port Mouton
50 59. Plot of heavy minerals against mean grain size for Green Bay
50 60. Opaque minerals as percentage of total heavy minerals for Port Mouton.
50 61. Pyroxene and staurolite as percentage of total heavy minerals for Port Joli
51 62. General map of Kings and Hartling bays
53 63. Coastal sectors 1 to 7
54 64. Beach profiles for Kingsburg and Hirtles beaches
55 65. Sediment budget model
56 66. Grain size distribution of till and basinal mud southwest of Mahone Bay
57 67. Isopach map of surficial sediments west of Cape LaHave
58 68. Isopach map of surficial sediments east of Cape LaHave
59 69. Thicknesses cored in acoustic unit d2
60 70. Rates of sedimentation of LaHave Clay
61 71. Drumlins in southwestern Mahone Bay

THE MARINE GEOLOGY OF THE INNER SCOTIAN SHELF OFF THE SOUTH SHORE, NOVA SCOTIA

Abstract

The innermost 10 km of the South Shore coast is described, showing that both bedrock and surficial geology are a continuation of that seen on land. The offshore geomorphology is essentially an extension of the Maritime peneplane, which has been modified to produce overdeepened basins, particularly in granites. The bedrock surface is cut by sinuous, discontinuous, and anostomosing channels up to 60 m deep.

A comprehensive account of late Wisconsinan and early Holocene stratigraphy and sedimentation in this coastal and inner shelf environment has been presented based on seismic profiles and the detailed study of sediments and fauna in 20 piston cores.

Although most sediment is derived through the erosion of till cliffs, the Holocene sediment budget suggests that much of the observed nearshore sand must have moved shorewards with the Holocene transgression.

Résumé

Une description des dix premiers kilomètres s'éloignant de la côte sud montre que la roche en place et les formations en surface sont un prolongement de ce que l'on observe sur la terre ferme. La géomorphologie au large de la côte est essentiellement le prolongement de la pénéplaine des Maritimes qui a été modifiée pour former des bassins surcreusés, particulièrement dans les granites. La surface de la roche en place est traversée par des chenaux sinueux, discontinus et anastomosés pouvant atteindre 60 m de profondeur.

Un rapport complet de la stratigraphie et de la sédimentation de la fin du Wisconsinien et du début de l'Holocène en milieu côtier et sur le plate-forme intérieure est présenté, fondé sur les profils sismiques et l'étude détaillée des sédiments et de la faune provenant de 20 échantillons prélevés par carottier à piston.

Bien que la plus grande partie des sédiments proviennent de l'érosion de falaises de till, le bilan sédimentaire de l'Holocène suggère qu'une grande partie du sable observé sur l'avant-côte a dû se déplacer vers la côte lors d'une transgression marine de l'Holocène.

SUMMARY

The marine geology of a 150 km segment of the inner continental shelf adjacent to the South Shore of Nova Scotia within 10 km of the coastline has been mapped using magnetometer data, high-resolution seismic reflection profiles, and surficial sediment samples. The bedrock geology is a seaward continuation of that seen on land, and the distribution of the Cambro-Ordovician Goldenville and Halifax Formations, Devonian granites and Mississippian Windsor Group has been mapped.

The morphology of the bedrock surface is shown on seismic reflection profiles as very rough on a small scale. The general trend is a continuation of the prominent Maritime peneplane which occurs on land and has been modified by glacial excavation to produce over-deepened basins. Such basins are best developed in granites, but are also found on the north-dipping flanks of anticlines in the Meguma Group.

SOMMAIRE

La géologie marine d'une portion de 150 km du plateau continental intérieur attenant à la côte sud de la Nouvelle-Écosse et située à moins de 10 km du littoral a été cartographiée à l'aide de données magnétométriques, de profils de sismique réflexion de haute résolution et d'échantillons de sédiments superficiels. La géologie de la roche en place est le prolongement vers la mer de la terre ferme; la répartition des formations de Goldenville et d'Halifax (Cambro-Ordovicien), des granites dévoniens et du groupe de Windsor (Mississipien) a été compilée sur carte.

D'après les profils de sismique réflexion, le modelé de la roche en place est très accidenté à petite échelle. Il a tendance à prolonger la pénéplaine prédominante des Maritimes que l'on trouve sur terre et a été érodé par les glaciers, qui ont surcreusé des bassins. Ces bassins sont plus prononcés dans les granites, mais on en trouve aussi sur les versants à pendage nord d'anticlinaux du groupe de Meguma.

The bedrock surface is cut by sinuous, discontinuous and anastomosing channels that are up to 60 m deep. These have an up-and-down talweg, suggesting that they are not fluvial, but are sub-ice meltwater channels or rinnentaler.

The glacial history of the area has been determined based on the interpretation of high-resolution seismic reflection profiles and over 20 piston cores. Environmental interpretations are based on sedimentology and the benthic foraminifera and dinoflagellate cyst assemblages in the cores; and the morphology of acoustic stratigraphic units. Age control is provided by radiocarbon dates and pollen assemblages.

Drumlinoid mid- or late Wisconsinan till is widespread on land in the eastern part of the study area. A discontinuous till sheet, probably late Wisconsinan in age, can be traced about 5 km seaward of the outermost headlands ("late till"). Beyond this, acoustic profiles show a complex sedimentary sequence overlying an older, dissected, possibly mid-Wisconsinan, till that mantles bedrock ("early till"). The oldest sediment overlying early till is acoustically transparent and is draped over the till surface. Study of piston cores indicate that it comprises an upward-fining sequence of gravel through sand to laminated mud deposited in a proglacial environment. It is overlain by acoustically stratified sediment that tends to fill depressions and may comprise outwash sands and gravels, which pass northwards into the late till. A major unconformity above these older sediments probably results from coastal planation following a late Wisconsinan lowering of sea level to around –120 m. Acoustically stratified sediments above the unconformity comprise gravels and sands passing upward into laminated muds, deposited in an ice-margin environment as late Wisconsinan ice retreated and sea level rose. Holocene sands and muds have subsequently accumulated in basins.

Surficial sediment distribution has been mapped using acoustic profiles and bottom samples. Muds accumulate only in sheltered bays and muddy gravelly sand occurs as a sediment veneer over till in the same bays. Sands are found on beaches and shore faces, and in basins on the innermost part of the open shelf, with a rapid transition to sandy gravels offshore.

Modal sand sizes increase seawards across the inner shelf from 3.5 phi nearshore to as coarse as 1 phi a few kilometres offshore. Except in enclosed bays, sand grain size distributions are negatively skewed, which suggests that fine sand and silt have been winnowed out. Sedimentary structures suggest that large amounts of sand are

La surface de la roche en place est cruesée de chenaux sinueux, distontinus et anastomosés pouvant atteindre 60 m de profondeur. Ces chenaux ont un talweg ondulé qui laisse croire qu'ils sont d'origine non pas fluviale mais qu'ils ont servi à charrier les eaux de fonte sous la glace.

La glaciation de la région a été déterminée en interprétant des profils de sismique réflexion à grand pouvoir résolvant et les résultats d'analyse de 20 prélèvements de carottier à piston. Les interprétations environnementales reposent sur la sédimentologie et les associations de foraminifères benthiques et de coques dinoflagellées présents dans les carottes; ainsi que sur la morphologie des unités stratigraphiques acoustiques. La datation est établie au moyen du radio-carbone et des assemblages polliniques.

Du till drumlinoïde du Wisconsinien moyen ou de la fin est courant sur terre, dans la partie oriental de la région étudiée. Une couche de till discontinue datant probablement de la fin du Wisconsinien peut-être retracée à environ 5 km en direction de la mer, dans la partie la plus saillante du promontoire (till le plus récent). Au delà, les profils d'analyse acoustique montrent une série complexe de couches sédimentaires recouvrant un till plus vieux, érodé par ruissellement, datant peut-être du Wisconsinien moyen qui recouvre la roche en place (till inférieur). Le sédiment le plus ancien recouvrant ce till inférieur, transparent à l'analyse acoustique, drape la surface de till. L'étude des prélèvements de carottier à piston révèle que cette couche comprend une séquence de gravier dont la granulométrie change vers le haut pour passer au sable puis à la boue laminée, déposée dans un milieu proglaciaire. Elle est recouverte de sédiments stratifiés, d'après l'analyse acoustique, qui tendent à remplir les creux et qui pourraient comporter des sables et des graviers d'épandage fluvioglaciaire se dirigeant vers le nord jusque dans le till supérieur. Une discordance importante au-dessus de ces vieux sédiments résulte probablement d'un aplanissement de la côte suite à une baisse de la fin du Wisconsinien d'environ –120 m par rapport au niveau de la mer. D'après les études soniques, les sédiments lités susjacents à la discordance seraient composés de sables et de graviers se transformant vers le haut en boues laminées déposées dans un front glaciaire à mesure qu'à reculé la glace de la fin du Wisconsinien et qu'à monté le niveau de la mer. Les sables et les boues de l'Holocène se sont par la suite accumulés dans des bassins.

La distribution des sédiments en surface a été cartographiée au moyen de profils d'analyse sismique et d'échantillons prélevés du fond. Les boues ne s'accumulent que dans les baies protégées, et le sable contenant de la boue et du gravier se trouve en tant que fine couche sédimentaire recouvrant le till, dans les mêmes baies. On trouve du sable sur les plages et les zones infratidales, ainsi que dans certains bassins de la partie du plateau en mer la plus rapprochée de la côte, passant rapidement à des graviers sablonneux au large.

La granulométrie modale des sables croît à mesure que l'on se rapproche de la mer sur tout le plateau littoral, passant de 3,5 phi le long de l'avant-côte à 1 phi, à quelques kilomètres du littoral. Sauf dans les baies protégées, la distribution granulométrique du sable décroît de façon oblique, ce qui laisse croire que les sables fins et les limons ont été occasionally transported in suspension, presumably by storm currents.

The erosion of till cliffs is the major source of sediment to the coastal zone. Cliffs are eroded most rapidly by storms during spring thaw.In fair-weather fine sediment eroded from cliffs is deposited on the upper margins of nearshore basins. In these basins, muds show a decrease in sand and coarse silt content away from the shallow margins. Silt laminae at the base of graded mud beds can be correlated between cores and suggest that fallout of sediment after storm resuspension on upper basin margins is the dominant depositional process within the basins.

The overall distribution of heavy minerals suggests that they are derived from nearby till and transported only short distances within the nearshore zone. Offshore there may be significant eastward longshore transport of sand. Clay mineralogy also parallels source-till mineralogy, but is not sufficiently distinctive to permit monitoring of sediment dispersion.

A Holocene sediment budget suggests that till cliff erosion is insufficient to account for observed nearshore sand; much of this sand must have moved shorewards with the Holocene transgression. Barrier beach history suggests this was accomplished mainly by catastrophic failure of beaches, and their subsequent re-establishment farther landwards.

éliminés. Les structures sédimentaires indiquent que de grandes quantités de sable sont à l'occasion transportées en suspension, présumément par des courants de tempête.

Les sédiments de la zone côtière proviennent surtout des falaises de till, plus rapidement érodées par les tempêtes durant le dégel du printemps. Lorsque le temps est beau, de fins sédiments descendant des falaises se déposent à la limite supérieure des bassins d'avant-côte. Dans ces bassins, la boue est caractérisée par une baisse de la teneur en sable et en silt grossier à mesure que l'on s'éloigne des limites du plateau en eaux peu profondes. Des lamelles de silt à la base des boues granuloclassées peuvent être corrléles d'une carotte à l'autre et laissent croire que le dépôt des sédiments après leur brassage par la tempête sur les bords supérieurs du bassin est la principale forme de sédimentation dans ces bassins.

D'après la répartition globale des minéraux lourds, ceux-ci viendraient du till qui se trouve à proximité et ne seraient déplacés que sur de courtes distances, dans la zone d'avant-côte. Au large, cependant, le sable pourrait être charrié sur de longues distances vers l'est, le long du littoral. La minéralogie des argiles est aussi parallèle à celle du till d'origine. Toutefois, elle n'est pas suffisamment différente pour permettre de contrôler la dispersion des sédiments.

Selon le bilan sédimentaires de l'Holocène, l'érosion des falaises de till ne peut expliquer la présence de sable à proximité du littoral; une grande partie doit donc s'être déplacée vers la côte durant la transgression marine de l'Holocène. D'après l'évolution du cordon littoral, ce déplacement aurait eu lieu surtout à cause d'une disparition catastrophique des plages et de leur reformation, plus près de la terre ferme.

INTRODUCTION

Purpose

This report presents the offshore geology along the South Shore of Nova Scotia, southwest of Halifax. The study area extends 150 km from St. Margaret's Bay southwest to Sable River, just east of Lockeport (Fig. 1). The most detailed work has been carried out within 10 km of the coast in water depths of less than 50 m but in places the study has extended over 30 km offshore.

The primary purpose was to map bedrock lithology, morphology of the bedrock surface, and the distribution of till and overlying postglacial sediments. This mapping provided an opportunity to study several specific scientific problems. The late Wisconsinan ice sheet probably extended a short distance seaward of the present coastline; we have attempted to determine the limits of this ice sheet and the nature and timing of deglaciation of the inner part of the continental shelf. Early Holocene sediments provide information on environmental conditions on the continental shelf, which are important to our more general understanding of water mass history off Atlantic Canada (Vilks and Rashid, 1976; Alam, 1979; Mudie, 1980; Hill, 1981; Scott et al., 1982). The history of relative sea level in Atlantic Canada, strongly dependent on glacial loading, is complex. Sea level data prior to 8000 BP on the Atlantic seaboard of Nova Scotia are presented: such data, however, are available only from submerged areas. The larger coastal bays provide accessible 'natural laboratories' for understanding the sediment distribution processes active on a storm-dominated continental shelf. The wealth of data obtained by seismic reflection profiling permits geomorphological interpretation of submerged terrestrial features in more detail than is possible on land.

General geological setting

Previous marine geological work in the region is summarized by Bartlett (1964), King (1970), Drapeau and King (1972), Cranston and Buckley (1972), King and MacLean (1976), Piper and Keen (1976), Vilks and Rashid (1977), and Barnes and Piper (1978). Bedrock geology is a continuation of that seen along the adjacent coast: Meguma Group slates and metagreywackes of Cambro-Ordovician age, intruded by Devonian granites and locally overlain by Carboniferous sediments. The bedrock surface is the prominent Maritime peneplane (Goldthwaite, 1924; King, 1972) modified by glacial erosion with the excavation of deep basins and the cutting of narrow sinuous channels (Barnes and Piper, 1978). A band of moraines 30 to 50 km offshore (Drapeau and King, 1972) appears to mark the floating terminus of the mid-Wisconsinan ice sheet, and intertongues seawards with the glaciomarine Emerald Silt (Parrott et al., 1980; King, 1980). Landward of the moraines are widespread sheet till and drumlin fields, partly planed off by the Holocene marine transgression. Basins and channels are partly filled by fluvioglacial gravels and early Holocene marine or lacustrine sediments. Gradually rising sea level has flooded successive basins. Surficial sediment distribution is largely a consequence of wave redistribution of sediment derived from coastal erosion of drumlins as sea level has risen.

Responsibilities of authors

This paper has been compiled and written by Piper, based on his interpretation of the original data and on unpublished theses and reports by the co-authors. Letson studied the surficial sediment in western Mahone Bay; Barnes the surficial sediment, till, and bedrock in eastern Mahone Bay; Iuliucci did much of the work in the Port Hebert area; Mudie did all the palynological work and compiled the biostragraphic data. Not all authors necessarily agree with all the interpretations that are presented.

Acknowledgments

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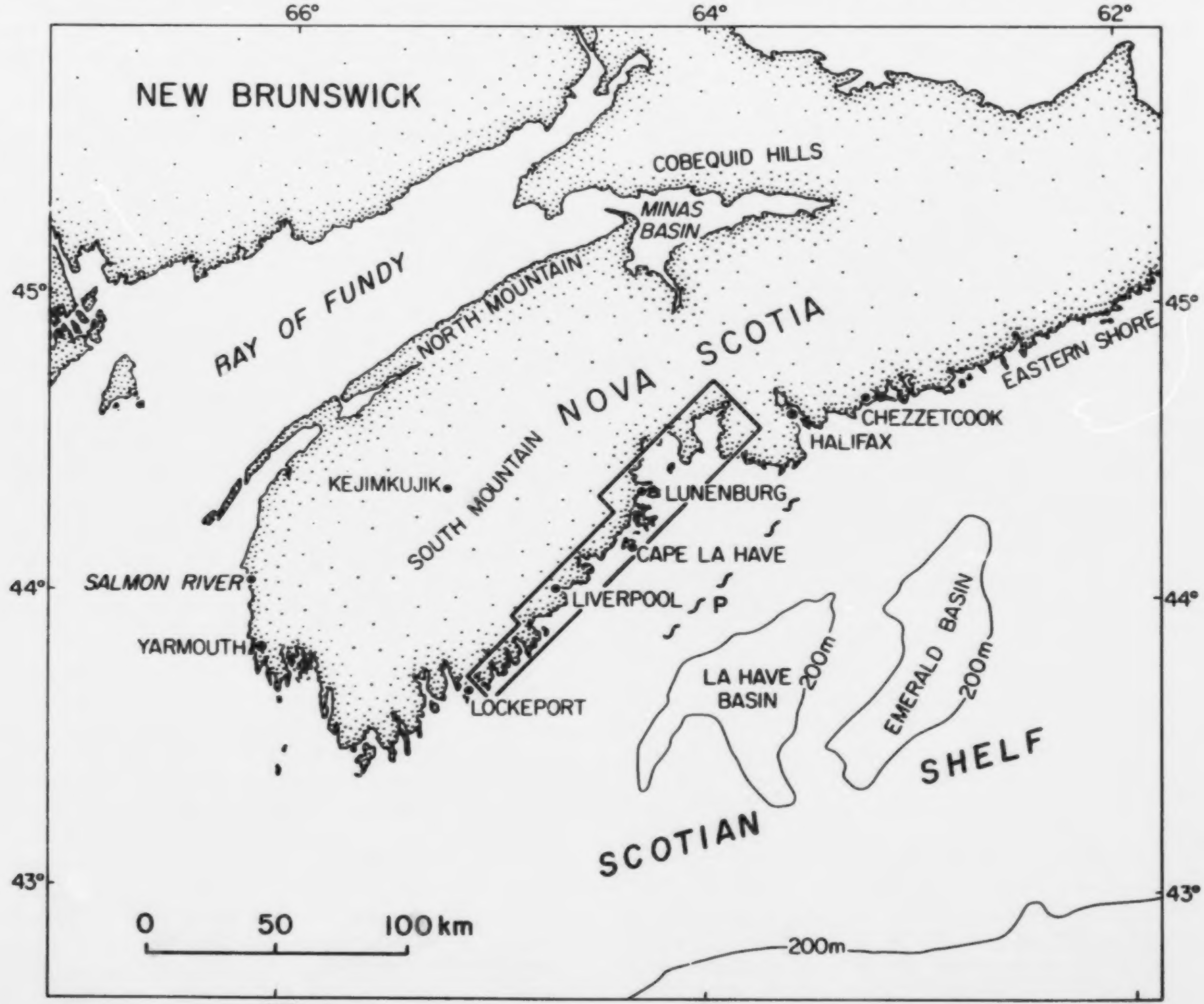

66°
64°
62°
NEW BRUNSWICK
COBEQUID HILLS
MINAS BASIN
BAY OF FUNDY
NORTH MOUNTAIN
45°
45°
NOVA SCOTIA
EASTERN SHORE
CHEZZETCOOK
HALIFAX
KEJIMKUJIK
SOUTH MOUNTAIN
LUNENBURG
CAPE LA HAVE
44°
SALMON RIVER
LIVERPOOL
P
44°
YARMOUTH
LA HAVE BASIN
200m
EMERALD BASIN
200m
LOCKEPORT
SHELF
SCOTIAN
43°
43°
0
50
100 km
200m
66°
64°
62°

Figure 1. Map of Nova Scotia and Scotian Shelf showing location of study area along the South Shore. P = Pennant Point moraine (Drapeau and King, 1972).

CFAV **Kapuskasing**. Nearshore work was largely carried out in rented fishing boats: we thank Clifford Dauphinee, Gus Henneberry, Art Webster, Norm Greek, Bobby Lohnes, Harry Doggett, and Jim Himmelman for their help. Summer student assistants included Lynn Smith, Lauchie Maugher, Clive MacKay, Emmet Urquhart, Robin Mann, Bill Cooper, Gil Whitehouse, Ned King, Ingrid Berger, Kevin Slauenwhite, John Easton, Geoff Camp, Steve Harnish, Karen Comstock, and Karen O'Brien. At various times Bruce Hewgill, David Bevan, and Tom Duffett maintained equipment and assisted in the field. Data from class projects by Peter Vilks, Ross Douglas, Steve Walker, Ned King, Bob Myers, Ingrid Berger, Garth de Mont and John Cullen have been included. David B. Scott of Dalhousie University identified and counted all our foraminiferal samples between 1976 and 1978. Our colleagues Basil Cooke, Eric Nielsen, Don Bidgood, Chris Beaumont, Lew King, Gordon Fader and Tony Bowen have provided important advice.

METHODS

The distribution of seismic reflection lines and bottom sample sites for this study is illustrated in Figure 2. Details of specific methods are given in the appropriate sections of this report. Nearshore surveys in sheltered waters (e.g. Mahone Bay, Green Bay) have been made from a 6 m portable Cape Island style boat, fitted with a Kelvin-Hughes MS26-B echo sounder. Navigation was by sextant fixes to known points on shore, and comparison of echo-sounder profiles with Canadian Hydrographic Service field sheets. Other nearshore surveys from 10 to 12 m fishing boats used radar-range navigation for underway work and sextant fixes for station work. Navigational accuracy therefore is dependent on the availability of targets and weather, but is usually accurate to 100 m for stations and 50 m for underway surveys on a constant course. These nearshore surveys obtained MS26-B (14.25 kHz) or 3.5 kHz reflection profiles for defining surface and near-surface sediments. Some total magnetic field intensity profiles were obtained using a Varian proton precession magnetometer. Sediment samples were obtained with Van Veen, Dietz La Fond, and Ekman grab samplers and gravity corers.

Larger ships were used to collect most offshore seismic reflection profiles, piston cores and box cores. Navigation was by radar within 5 to 10 km offshore, and by Decca farther seaward. Decca navigational accuracy is estimated at 400 m for underway surveys on a constant course. Nearshore seismic reflection profiles were collected using a Teledyne sparker and Aquadyne eel; farther offshore, the Nova Scotia Research Foundation Corporation (NSRFC) V-fin deep-towed sparker system was used (Bidgood, 1974). Unfortunately, the differences between this system and the Huntec DTS system used by King (1980) did not always permit a precise correlation of acoustic facies between the two systems.

Detailed shallow-water surveys in Mahone Bay were carried out by SCUBA diving. Positions were determined by reference to a rope laid out on the sea floor, with its ends positioned by sextant angles.

The data used in compiling many of the figures in this report, such as those showing depth to bedrock and surficial sediment distribution, show a great deal of small-scale variation. Both navigational inaccuracy and the 1 to 5 km line spacing made it impossible to depict all of this detail in the figures; the reader, therefore, should pay careful attention to the data base from which each figure has been prepared.

PHYSIOGRAPHY

The overall trend of the Atlantic coastline of Nova Scotia is west-southwest (Fig. 1), approximately parallel to both the strike of the Meguma basement and the continental shelf break. Along the South Shore (Fig. 3) the coast is indented by a series of depressions trending normal to the coastline (south-southeast). From east to west the largest inlets are Halifax Inlet, St. Margaret's Bay, Mahone Bay, Lunenburg Bay, LaHave estuary, Green Bay, Medway Harbour, Liverpool Bay, and Port Mouton. These depressions commonly have overdeepened basins, and Halifax Inlet, St. Margaret's Bay and Mahone Bay have pronounced sills. The west sides of several of these depressions rise more steeply than the east.

The structural trend (west-southwest) of the Meguma rocks is reflected by morphology on land in some places, such as the Rose Bay area and Big Tancook Island. At sea, this trend is represented by a series of ridges and depressions which are well developed to the south of Lunenburg as far seaward as the 50 m isobath (Fig. 3). Some of these ridges terminate abruptly (e.g. Ironbound Bank, south of Lunenburg). A transverse south-southeast trend dominates seafloor relief in some areas, notably between Port Hebert and Liverpool Bay (Fig. 3).

Seaward of the 60 m isobath (Fig. 5), bathymetry becomes irregular with few linear trends. There is a series of sinuous valleys 1 to 2 km wide and 20 to 50 m deep that are locally discontinuous and in places widen into flat-floored basins. Isolated shoals rise above the plateau-like seafloor between the valleys.

Drumlins, which are conspicuous relief forms on land, are well preserved only in sheltered waters of St. Margaret's and Mahone bays, where they are commonly flat topped (Fig. 6). Extensive coastal shoals have developed offshore from areas where there are abundant drumlins on land,for example in Lunenburg Bay (Fig. 7, 8). Similar eroded till platforms are developed off drumlin islands and headlands. However, broad coastal shoals also occur in a few areas such as Medway Harbour where drumlins are sparse on land.

Steep-sided channels, typically 200 to 400 m wide and 20 to 50 m deep, are common in some nearshore regions (Fig. 9). They cross the sills at the entrance to St. Margaret's and Mahone bays, and are clearly seen in northeastern Mahone Bay and in Lunenburg Bay (Fig. 7). In places they are discontinuous. They are similar to the valleys seaward of the 50 m isobath (Fig. 5). Overdeepened scours occur between islands or shoals that form constrictions in areas such as Mahone Bay (Fig. 6).

Flat-floored sediment basins which slope gently seawards are common. They occur in a variety of water depths:

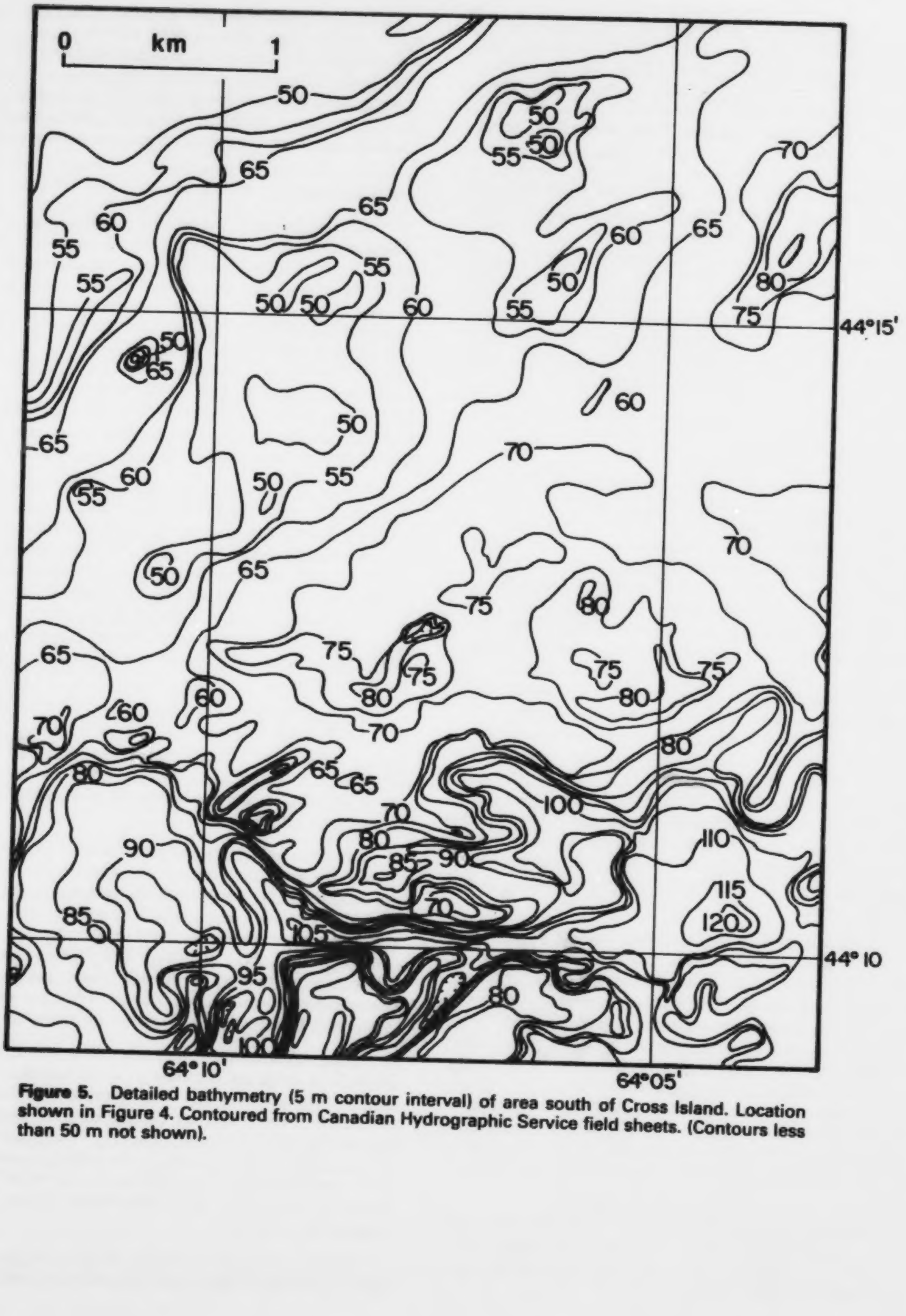

0 km 1
50
50
50
55
70
65
65
60
55
55
60
65
80
50
50
55
60
55
75
44°15'
50
65
60
65
50
70
60
55
50
55
70
50
65
75
80
65
75
75
75
80
75
70
60
60
80
70
65
65
100
80
70
110
90
80
85
90
115
85
70
120
105
44° 10
95
80
100
64° 10'
64°05'

Figure 5. Detailed bathymetry (5 m contour interval) of area south of Cross Island. Location shown in Figure 4. Contoured from Canadian Hydrographic Service field sheets. (Contours less than 50 m not shown).

for example, 50 to 70 m in St. Margaret's Bay; 29 to 40 m in Mahone Bay; 25 to 30 m in outer Lunenburg Bay; and 60 to 70 m south of Cross Island. In most cases, basin flanks rise steeply to between the 20 and 10 m isobaths, where the flatter nearshore shoals begin (Fig. 8).

BEDROCK GEOLOGY

Bedrock geology of the innermost part of the Scotian Shelf is a continuation of that observed on land (King and MacLean, 1976). The rock types present (Fig. 10) are slates and metagreywackes of the Meguma Group (divided into the Goldenville Formation quartzites and the Halifax Formation slates), Devonian granite intrusions, thin Carboniferous Windsor Group sediments, and lower Mesozoic mafic intrusions (notably the Shelburne Dyke; Papezik and Barr, 1981).

Bedrock outcrops on land are sparse in many parts of the South Shore (particularly east of LaHave estuary) due to a thick cover of till. A series of major, plunging anticlines and synclines has been mapped in the Meguma Group (Taylor, 1969), with a spacing of 1 to 10 km, but smaller scale folds and faults are difficult to map because of the lack of marker horizons. In some cases, however, the folds appear to have an *en echelon* pattern (Jones, 1975). Cameron (1956) suggested that the prominent south-southeast geomorphic trend of much of the Atlantic coast is due to faults along that trend, although few such faults have been identified by mapping on land. In some cases there is insufficient outcrop to map accurate limits of the Devonian granites and the Windsor Group sediments.

The distribution of nearshore bedrock can often be inferred from the adjacent land. In a few cases, samples of submarine talus overlying bedrock can be used for mapping but these must be distinguished from allochthonous clasts derived from tills. Reflection characteristics of seismic profiles can occasionally be used as a guide to bedrock type; Barnes (1976) was able to recognize thin Windsor Group sediments in northeastern Mahone Bay with this approach.

Magnetic field measurements, however, proved to be the most diagnostic data for mapping offshore bedrock geology. For logistic reasons, data density and quality were variable. There is a detailed grid survey in western Mahone Bay

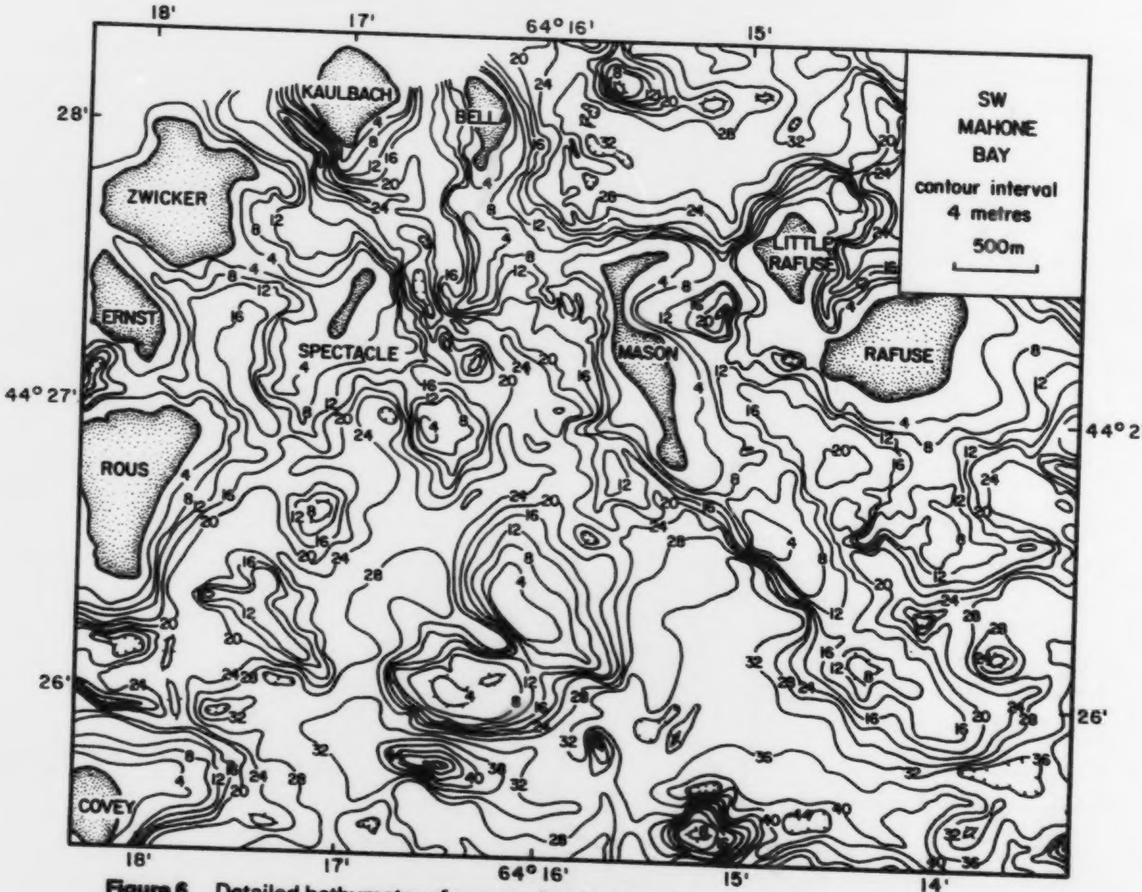


Figure 6. Detailed bathymetry of area studied in detail by Letson (1980) in southwest Mahone Bay. Contour interval 4 m. Contoured from Canadian Hydrographic Service field sheets. Location shown in Figure 4.

(Fig. 11) and a reasonable line density seaward of St. Margaret's Bay (Piper and Keen, 1976), in eastern Mahone Bay (Fig. 12), around Lunenburg Bay (Fig. 13), and from Liverpool Bay to Sable River (Fig. 14). All data presented are unprocessed, with no diurnal or regional field corrections, since these are small compared with the observed anomalies. About half the data are from areas in which bedrock geology can be extended from the adjacent land geology.

Smooth magnetic fields varying by less than 30 nT over 1 km characterize areas of granite and Goldenville Quartzite (Fig. 12; Piper and Keen, 1976). Some areas of Halifax Slate also have relatively smooth fields (variation of 70 nT over 1 km, for example profile G-G′, Fig. 13) but many areas of Halifax Slate have anomalies with amplitudes that range from 100 to as much as 1000 nT, and wavelengths typically ranging from 300 to 3000 m. Anomalies with amplitudes of more than 200 nT can be traced from one survey to another and are parallel to the strike of bedrock (Fig. 11; Nova Scotia Research Foundation, 1969), although they may change their detailed character. Even with a close line spacing, most smaller anomalies can be traced only a few hundred metres (NSRF, 1969). The Shelburne Dyke (Fig. 10) gives a large positive anomaly of 500 nT (Fig. 13, Line A; and Fig. 15).

Some large anomalies in the Halifax Slate in the Lunenburg area (Fig. 13) occur at the crests of anticlines. These anticlines are frequently mineralized, gold being the most important economic mineral. Pyrrhotite is a common constituent of mineralized veins (Graves, 1976) and may be responsible for the high magnetization of many anticlines. A negative magnetic anomaly is associated with anticlinal axes with a core of Goldenville Quartzite either outcropping or at shallow depth (e.g. Mosher Island Anticline, Fig. 13, Line A). Halifax Slate generally forms a positive anomaly relative to both Goldenville Quartzite and granite. No method was found to recognize unmineralized anticlines and synclines within the Meguma Group (Fig. 11).

In both western Mahone Bay (Fig. 11) and Lunenburg Bay (Nova Scotia Research Foundation, 1969), linear magnetic anomalies parallel to the regional strike of bedrock are terminated or offset along south-southeast discontinuities which locally have large positive anomalies. In Lunenburg

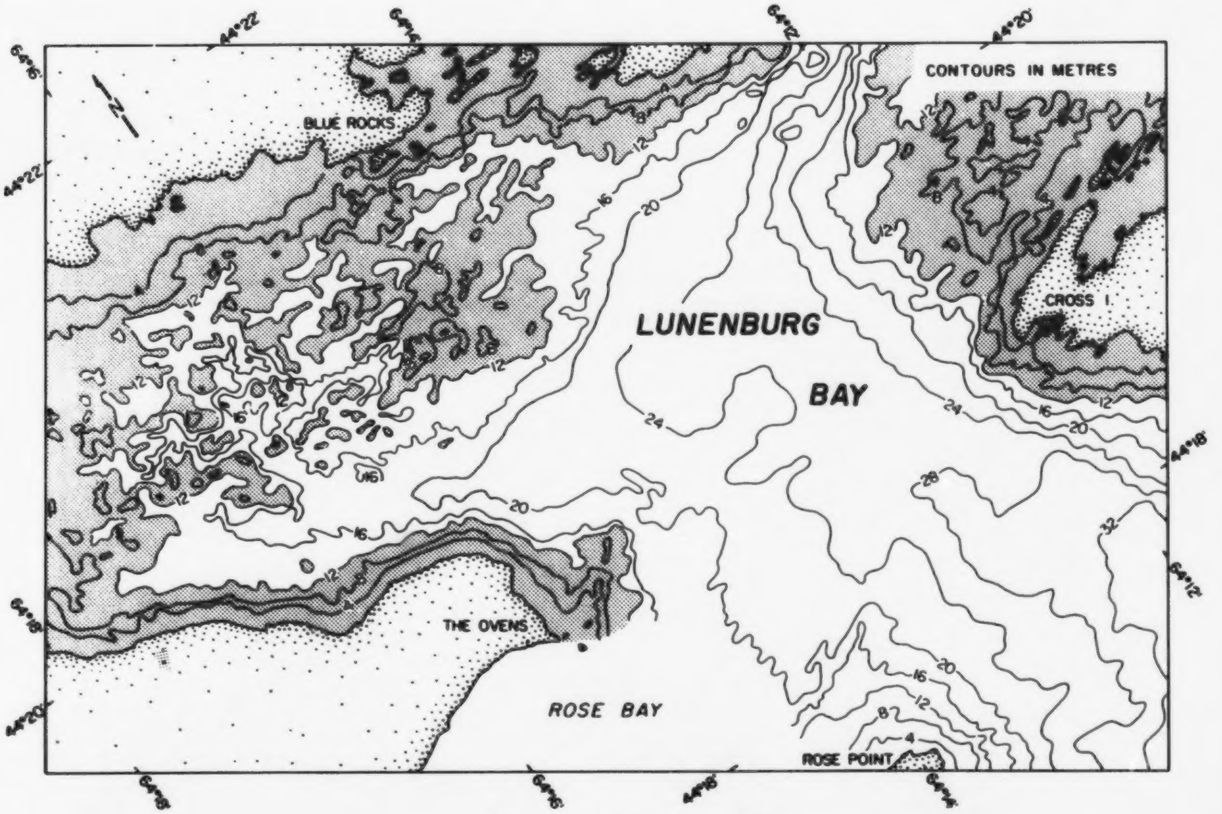


Figure 7. Detailed bathymetry of Lunenburg Bay contoured at 4 m interval from Canadian Hydrographic Service field sheets. Areas less than 12 m deep are stippled. Location shown in Figure 4.

Bay, these offsets appear to have a sinistral slip component (Nova Scotia Research Foundation, 1969). They are interpreted as faults, locally with pyrrhotite mineralization. A similar fault may mark the western edge of St. Margaret's Bay (Piper and Keen, 1976). Elsewhere, our line spacing is too great to recognize faults with such trends.

The distribution of Halifax Slate south of St. Margaret's Bay is readily mapped, but granite and Goldenville Quartzite most often cannot be distinguished with certainty (Piper and Keen, 1976). The distribution of granite, Goldenville Quartzite, and Halifax Slate has been mapped in Mahone Bay (Fig. 10). In the Lunenburg-LaHave area, mineralized anticlines and other anomalies in Halifax Slate can be traced considerable distances along strike, allowing extrapolation of geological structure seen on land. The most easterly outcrop of the Shelburne Dyke is on West Ironbound Island (Fig. 10); it may be present farther east, but is not known to outcrop, and cannot be distinguished magnetically from mineralized Halifax Slate. Barnes (1976) believed that a prominent linear topographic and magnetic feature southeast of Big Tancook Island in Mahone Bay might be the continuation of the dyke (Fig. 15), although it is not on strike with the Shelburne Dyke, and we saw no other evidence for a dyke in the Lunenburg Bay area.

Offshore from Medway Harbour, magnetically rough Halifax Slate can be distinguished from a magnetically smooth unit which is interpreted as Goldenville Quartzite on the basis of nearby land geology. Between Liverpool Bay and Port Mouton, Halifax Slate is easily recognized but mapped boundaries between Goldenville Quartzite and granite are less certain. Between Port Joli and Sable River (Fig. 10, 14), two areas are differentiated on the basis of magnetic field character. East of Port Hebert, the magnetic field is very smooth, suggesting that the Port Mouton pluton extends offshore, and that the Meguma outcrops at Port Joli are merely a large roof pendant. West of Port Hebert, a large magnetically smooth area might be a continuation of the Port

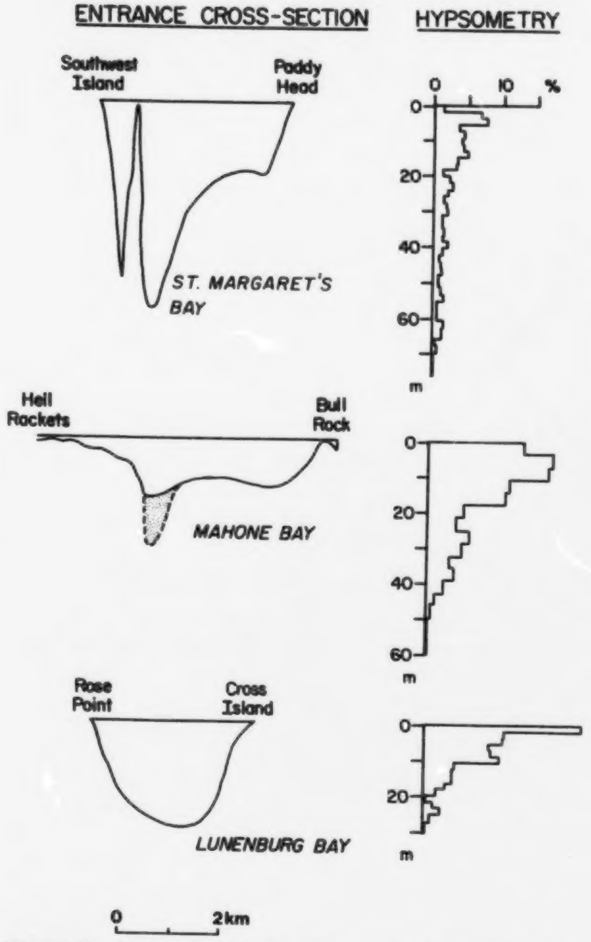


Figure 8. Hypsometric diagrams of St. Margaret's Bay, Mahone Bay (north of outer sill), and Lunenburg Bay (north of Cross Island-Rose Point), with cross sections showing morphology of narrowest and shallowest part of entrance to each bay. Sediment-filled channel shown by stipple.

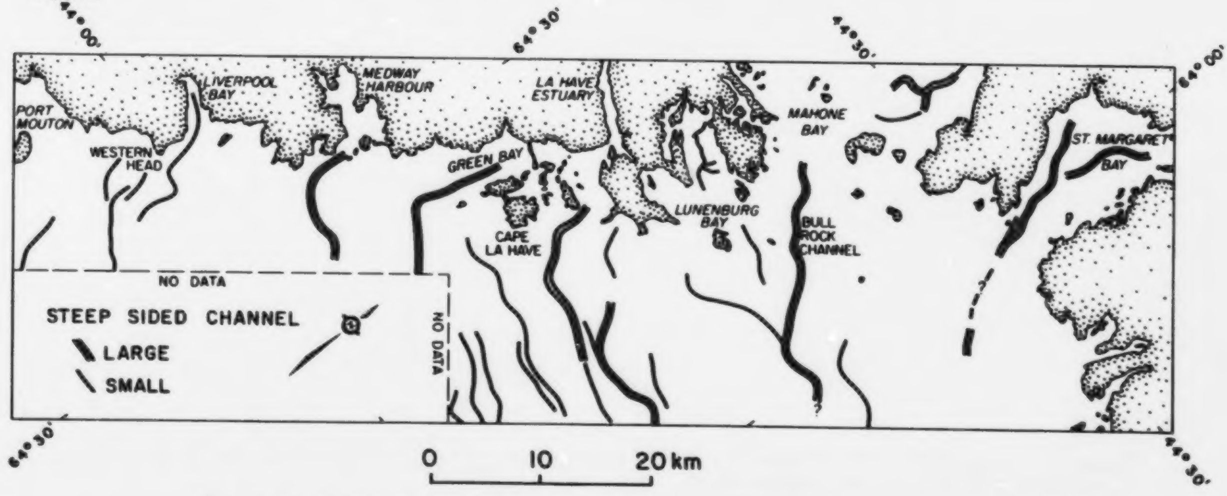


Figure 9. Distribution of steep sided, narrow channels, interpreted as rinnentaler.

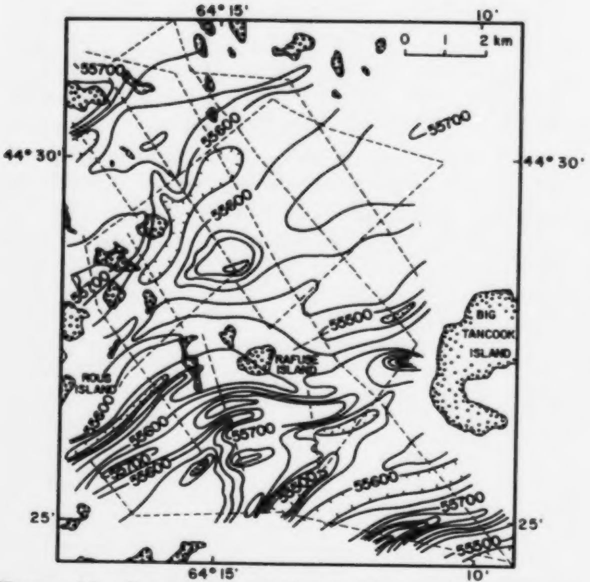

64° 15'
10'
0 1 2 km
55700
55600
55700
44° 30'
44° 30'
55600
55500
BIG TANCOOK ISLAND
RAFUSE ISLAND
ROUS ISLAND
55700
55600
55700
55600
55700
55500
25'
25'
64° 15'
10'

Figure 11. Contoured total magnetic field, western Mahone Bay. Dashed lines show location of profiles. Note the line of discontinuity in anomalies running from the northwest to the southeast corner of the figure. Units are in nanoTeslas.

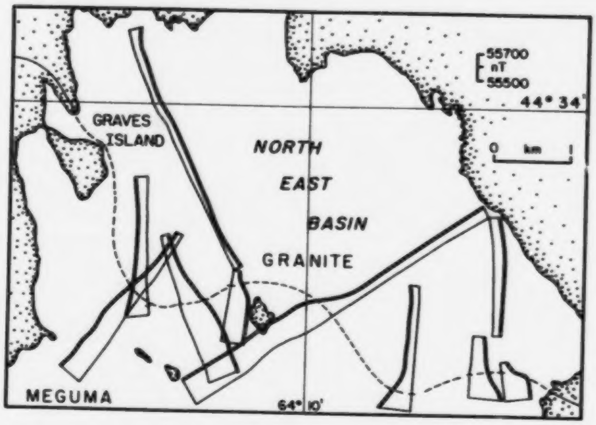

55700
nT
55500
44° 34'
0 km 1
GRAVES ISLAND
NORTH
EAST
BASIN
GRANITE
MEGUMA
64° 10'

Figure 12. Magnetic profiles, northeast basin of Mahone Bay, showing location of granite-Meguma contact.

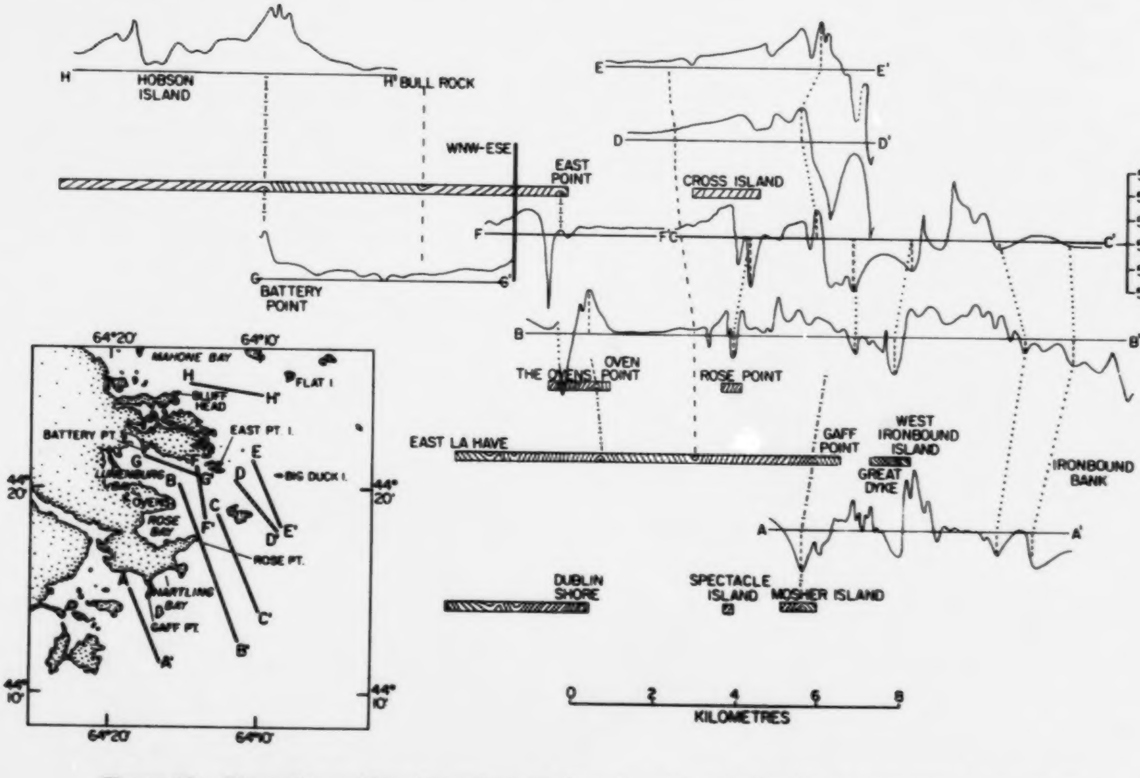


Figure 13. Magnetic profiles, Lunenburg region, showing relationship to structures in the Halifax Formation. Land geology after Taylor (1969).

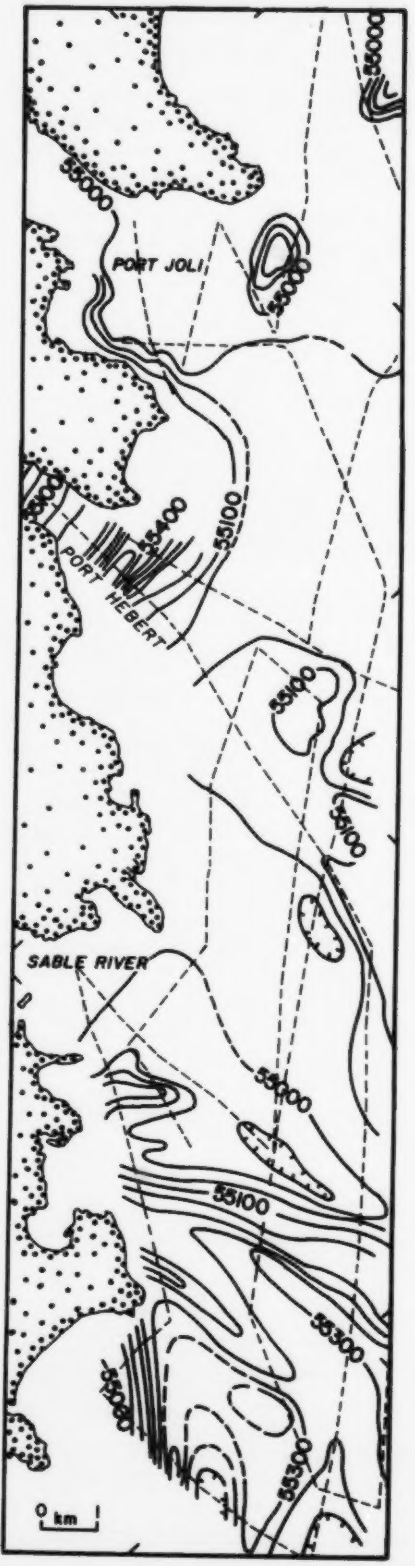

55000
PORT JOLI
55000
55100
55400
55100
PORT HEBERT
55100
55100
SABLE RIVER
55000
55100
55300
55000
55300
0 km 1

Figure 14. (Left) Contoured total magnetic field, Port Hebert region. Dashed lines show location of profiles.

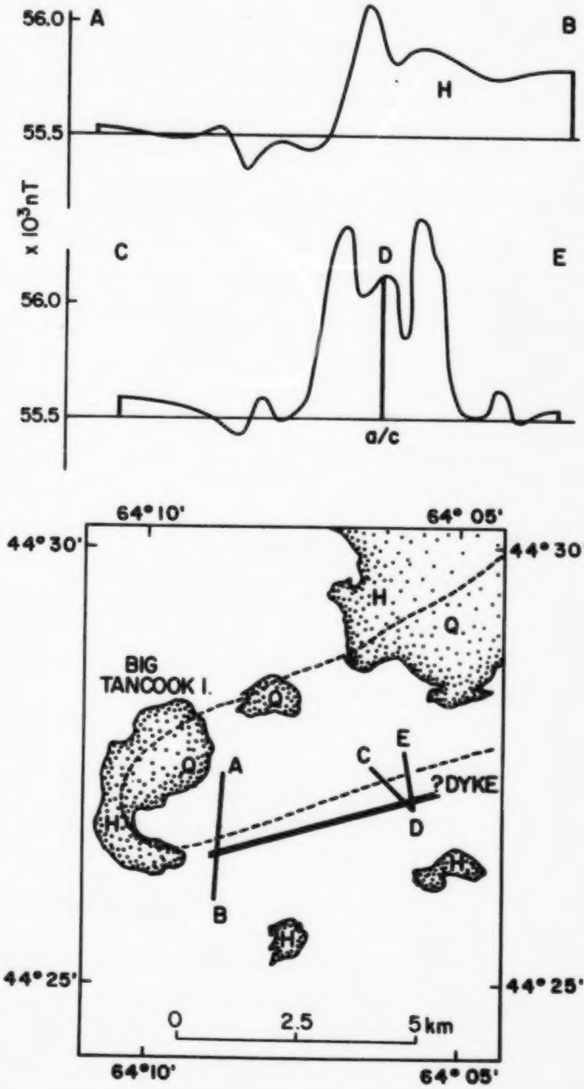


Figure 15. Magnetometer profiles across a possible dyke east of Big Tancook Island, Mahone Bay. H = Halifax Slate, Q = Goldenville Quartzite (a/c indicates course change).

Mouton pluton, but is probably Goldenville Quartzite. In the axes of the synclines in this area the magnetic field is rough (Fig. 10), indicating the presence of slate.

MORPHOLOGY OF THE BEDROCK SURFACE

Description

The depth of the bedrock surface below present sea level is shown by generalized contours in Figure 16 which is based on the interpretation of seismic reflection profiles and known bedrock outcrops. Both data sources show that the bedrock surface is rough on a small scale (Fig. 17-20).

The two prominent features shown in Figure 16 are the abundance of overdeepened basins, and the presence of sinuous, discontinuous, anastomosing, narrow valleys cut deeply into bedrock which generally trend to the southeast (Fig. 9). Sedimentation has partially infilled both these features which are less clearly seen in the bathymetry (Fig. 3).

Three small overdeepened basins occur at Port Mouton, with sill depths increasing eastwards from 30 ms to 50 ms two-way travel time, and a fourth small basin occurs south of Mouton Head. A deep basin lies beneath Liverpool Bay, but the amount of overdeepening is uncertain because of difficulties in penetrating the overlying sediments with the seismic systems used. There is another overdeepened basin to the east, south of Blueberry Point. All of these basins are developed on granite, and most lie near the edge of granitic stocks.

East of Blueberry Point, bedrock is predominantly Halifax Slate with Goldenville Quartzite close to shore. Bedrock ridges are developed parallel to the strike of the Meguma Group, approximately west-southwest, on the southward-dipping flanks of anticlines, whereas the north-dipping flanks form parallel depressions which are partly filled by sediments. This morphologic pattern extends as far east as the granite boundary southwest of St. Margaret's Bay (Fig. 10).

Deep, more or less continuous, channels are common between Port Mouton and St. Margaret's Bay (Fig. 9). The most prominent occur: (i) south of Western Head, (ii) in Liverpool Bay, (iii) south of Medway Harbour, (iv) in Green Bay, (v) in the LaHave estuary, (vi) in Lunenburg Bay, (vii) in

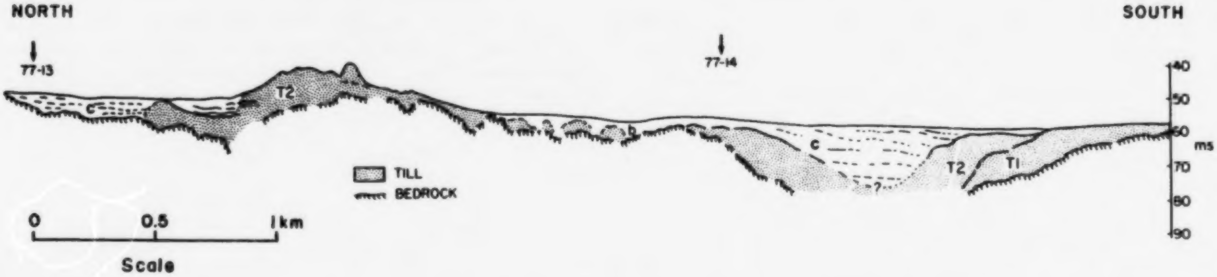


Figure 17. Line drawing of shallow-towed v-fin seismic reflection profile, LaHave estuary. Acoustic unit c (?or b) interfingers with and overlies late till (T2) and overlies early till (T1). Piston cores 77-13 and 77-14 are indicated. Location shown in Figure 21.

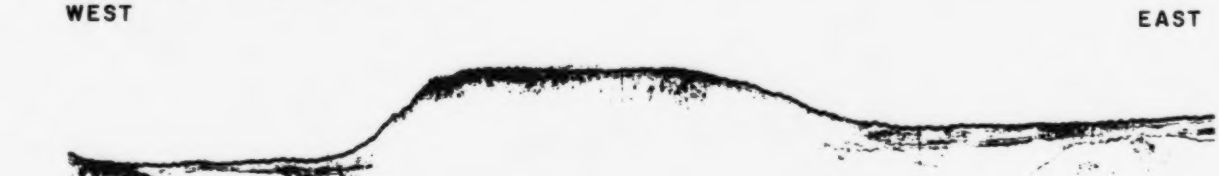


Figure 18. Photograph and interpretative line drawing of seismic reflection profile south of Cross Island showing late till overlying acoustic unit a and passing laterally into acoustic units b and c. Location shown in Figure 21. B = bedrock, T = early till; a, b and c are acoustic units.

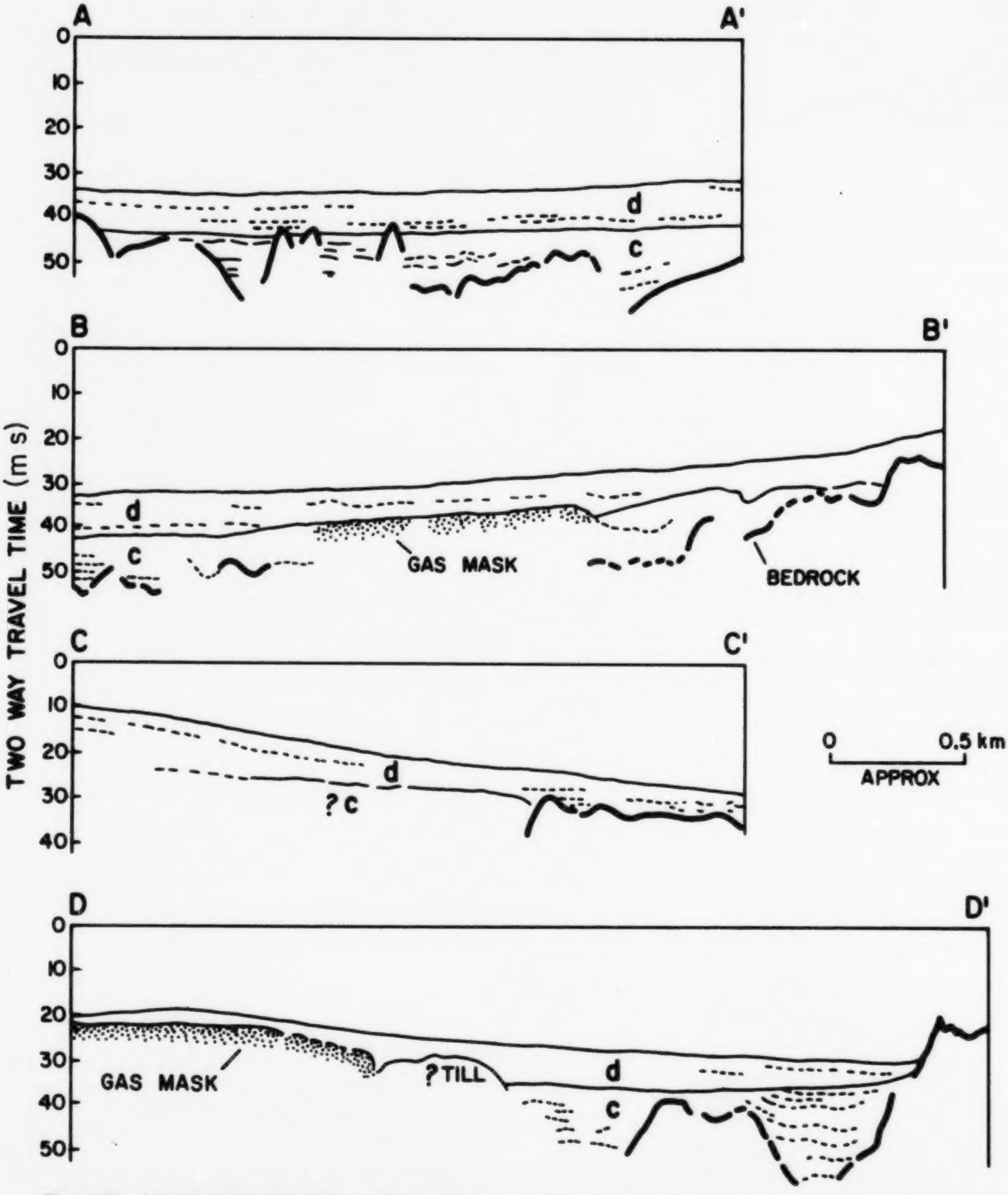

A
A'
B
B'
C
C'
D
D'
TWO WAY TRAVEL TIME (m s)
0
10
20
30
40
50
d
c
GAS MASK
BEDROCK
?c
?TILL
0
0.5 km
APPROX

Figure 19. Line drawings of 3.5 kHz profiles in Port Mouton area showing character and distribution of acoustic units c and d. Profiles located in Figure 30.

Bull Rock Channel south of Mahone Bay, and (viii) in St. Margaret's Bay. The width of these channels is partly controlled by their intersection with the west-southwest ridges. The channels are commonly sinuous. Although their detailed course does not appear to be structurally controlled, their general trend commonly follows lines of structural weakness. Western Head channel, running southeast, is parallel to several bedrock ridges in this region and is probably related to faults or joints. The Green Bay channel runs almost along geological strike. Lunenburg Bay and Bull Rock channels are developed along possible south-southeast faults (Fig. 11, 13). Many channels are partly filled by till, but commonly a steep sided valley, continuous with the narrower areas of bedrock valley, is cut in till. Between Mouton Head and Cape LaHave, most of the valleys can be traced seaward only as far as the 60 m isobath. To the south of Lunenburg, they extend almost to the line of moraines (King et al., 1972), in water depths as great as 130 m.

In northeast Mahone Bay, a deep basin occurs in a small area of granite. This is linked by a series of deep sinuous valleys to a large irregular basin west and south of Big Tancook Island (Fig. 3). The degree of structural control of this larger basin is uncertain (Fig. 10). The southern part of the basin lies on the north flank of the Heckman Island Anticline, the south flank of which forms the shallow outer sill at the entrance to the bay. The northern part of the basin lies over the westward and northward dipping margins of the plunging Tancook Anticline.

A deep basin has been excavated in granite in St. Margaret's Bay. It has a steep western margin but rises more gradually to the northeast. The deepest parts of the basin, however, are sinuous steep-sided channels cut below the level of the basin floor. The sill at the entrance to St. Margaret's Bay (which is cut by a narrow channel) is not a prominent feature on the bedrock surface.

Interpretation

The pre-Pleistocene bedrock surface of the South Shore was probably a peneplain sculptured by fluvial processes during the Tertiary (King, 1972). The morphological evolution of the bedrock surface during Pleistocene glaciation appears to be the result of two distinct processes, glacial quarrying and meltwater erosion, both of which were concentrated in pre-existing major river valleys. These pre-glacial valleys probably acted as conduits funnelling major ice flows. Quarrying and plucking by glacial ice excavated depressions where joint patterns were favourable, notably in some granite areas and on the north-dipping flanks of Meguma anticlines (Goldthwaite, 1924), particularly in lithologies that include some greywacke.

Steep sided sinuous channels with irregular talwegs (long profiles) cut both till and bedrock. Barnes (1976) and Barnes and Piper (1978) have proposed that in Mahone Bay these valleys are rinnentaler that were cut subglacially by running water. In shallower water some of these channels may also have a subaerial history. They are too narrow and sinuous to be eroded by glacial ice, but their irregular 'up and down' talweg (Barnes and Piper, 1978) and discontinuous, anastomosing pattern (Fig. 9) suggest their origin is not solely fluvial.

Both basins and channels are found in regional depressions, which are probably related to pre-glacial drainage patterns. Glacial quarrying is most efficient in ice streams flowing through broad valleys (Flint, 1971) and subglacial meltwater will also be concentrated in these valleys. A complex history of valley cutting is probable. Those channels that cut till must be younger than the last glacial advance in the area, but it is unlikely that all the glacial erosional features date from the late Wisconsinan. The depth of some of the channels, incised 40 m into bedrock, required more time for erosion than would be expected during a single glacial retreat.

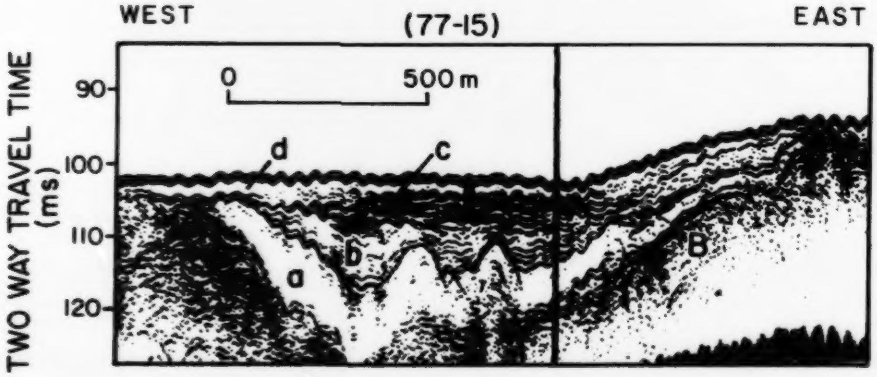


Figure 20. Seismic reflection profile from Bull Rock Channel near core 77-15 showing bedrock (B) and acoustic units a, b, c and d. Location shown in Figure 21. Core 77-15 is 500 m south of the profile in a location with a similar acoustic sequence: vertical bar shows the approximate projection.

Thus, at least some of the channels are older, and may have been repeatedly flushed and refilled by sediment during successive glaciations. The channels aided and accelerated the glacial quarrying process, while the larger depressions in which they occured concentrated sub-glacial melt water during deglaciation.

LATE WISCONSINAN AND EARLY HOLOCENE SEDIMENTATION

Glacial stratigraphy: existing concepts

The timing and character of Wisconsinan ice advances in the Maritimes are not yet known with certainty. The stratigraphic record on land in Nova Scotia was discussed by Nielsen (1976), Grant (1977), Prest (1977), Stea (1980, 1982), Stea and Fowler (1981), and Grant and King (1984). A widespread red till sheet overlies scattered organic beds ascribed to isotopic stage 5. This till sheet has a northerly provenance, including clasts from New Brunswick. It is overlain in places by a hybrid till, soils or organic beds some of which yield dates in the range of 32 000 to 39 000 years. Younger tills have local derivations from ice caps within the Atlantic Provinces (Grant and King, 1984). Postglacial sediments suggest rapid deglaciation between 16 000 and 11 000 BP (Prest and Grant, 1969).

A line of moraines on the Scotian Shelf (King et al., 1972; Drapeau and King, 1972) marks the grounding line of a mid-Wisconsinan ice shelf (L.H. King and G.B. Fader, personal communication, 1983).

Quinlan and Beaumont (1981, 1982) have modelled glacio-isostatic sea level changes in the last 20 000 years in Atlantic Canada. Their model suggests that the classical late Wisconsinan (18 000 BP) ice margin was close to the present coastline with a maximum sea level lowering of 50-60 m on the Scotian Shelf. King (1970) recognized a widespread terrace at –120 m on the Scotian Shelf, which appears to mark the lower limit of reworking of till and glaciomarine sediment, and which is interpreted as marking the maximum Wisconsinan lowered stand of sea level.

Thin and commonly coarse loose tills of apparently local derivation occur throughout the South Shore region, comprising granite or Meguma detritus (Nielsen, 1976). This till occurs locally as drumlins, as for example, in northern St. Margaret's Bay, or at Port Joli. The extensive Lunenburg drumlin field (Flint, 1971) lies between St. Margaret's Bay and LaHave estuary. Most of the drumlins consist of a red till (Lawrencetown Till of Stea and Fowler, 1981) including a variety of far-travelled lithologies: including basalt from North Mountain, granites and metamorphic rocks from the Cobequid Hills, and Carboniferous and Triassic sediments from central Nova Scotia (Nielsen, 1976). This correlates with the widespread early to mid-Wisconsinan red till sheet elsewhere in Nova Scotia (Grant and King, 1984). Around LaHave estuary, a few of the drumlins comprise predominantly Meguma lithologies (Slate Till of Stea and Fowler, 1981).

A well consolidated grey till beneath some of the drumlins in the Lunenburg area (Nielsen, 1976, p. 37; Hartlen Till of Stea and Fowler, 1981) may be pre-late Wisconsinan, as may also be the Bridgewater Conglomerate (MacNeill, 1972), but there are neither dates nor lithostratigraphic relationships to confirm this. Regional variations in grain distribution, pebble type and heavy mineral of tills were described by Grant (1963) and Nielsen (1976).

Stea (1982) studied the lithology, texture and geochemistry of tills in central Nova Scotia, north of the eastern part of the South Shore. He recognized five distinct till units: (1) Miller Creek Till (>52 000 BP) deposited by flow across the Cobequid Highlands and equivalent to the widespread red till elsewhere in Nova Scotia; (2) East Milford Till (>38 000 BP) deposited by ice from New Brunswick; (3) Hants Till, deposited by ice flow across the Cobequids in the Late Wisconsinan; (4) Bennet Bay Till, deposited by flow from North Mountain, Nova Scotia, in the Late Wisconsinan, prior to 14 000 BP; and (5) Rawdon Till deposited by westward flowing ice, about 12 000 BP. According to Stea (1982), the late Wisconsinan ice margin probably extended south of the present Nova Scotian coastline between about 38 000 and 25 000 BP, with later ice flows being much more localized in extent (till units 4 and 5).

Acoustic stratigraphy

Introduction

Acoustic stratigraphy is best determined in water depths in excess of 50 m, where multiples on the graphic record do not interfere with the signal. Well-defined acoustic stratigraphies have been established for the area south of Cross Island; the area from LaHave estuary to the approaches to Mahone Bay; within Mahone Bay and St. Margaret's Bay; and the Port Mouton-Liverpool Bay area. These are described and discussed separately, and a synthesis is presented. Thicknesses are given in milliseconds of two-way-travel time: 1 ms is equivalent to 0.75-1 m stratal thickness. Cores that provide evidence of the lithologies present are mentioned; core data are discussed in detail in another section.

South of Cross Island

The area south of Cross Island has been used as a type area for acoustic stratigraphy. V-fin deep tow profiles have been collected at a 2 km line spacing extending to the 120 m isobath, some 25 km offshore (Fig. 21). Over much of the area, bedrock or till is exposed on the sea floor. Younger sediments are preserved in basins and in the narrow steep-walled valleys (Fig. 22).

A discontinuous till unit (T1), recognized by its generally diffuse unstratified acoustic signature (Parrott et al., 1980), rests directly on bedrock (Fig. 23). It is referred to as the early till and appears to extend seaward to the Pennant Point moraine (Drapeau and King, 1972). The lowest prominent acoustic unit (a) above till is a transparent unit that drapes over the irregular till surface, with little thickness change from highs to basins (Fig. 24). There are regional variations in thickness from 5-10 ms, with thicker sequences farther offshore, and close to the major bedrock transverse depressions (Fig. 25). Except in valleys and basin centres, the top of acoustic unit a is erosional. There is nothing to suggest that it was originally deposited only in basins and valleys; it was probably originally more widespread, and has been largely removed by subsequent erosion. Cores from unit a comprise several metres of laminated cohesive clays passing downward into sands and gravels (Fig. 26).

Unit a is overlain by a stratified unit b in channels in the northern part of this type area. Unit b partly onlaps and drapes on basin or channel margins (Fig. 20, 24). In the Bull Rock Channel south of Pearl Island, an acoustic mask due to gas is developed in unit b where the sequence is thick (Fig. 24). In the southern part of the survey area, typical developments of unit b are absent; its only trace is a strong single or double reflection at the extreme bottoms of valleys (e.g. Fig. 23), which may be an artifact due to focussing of the seismic signal.

Both units a and b are overlain unconformably by an evenly stratified ponded succession, unit c, about 10 ms thick, that appears acoustically similar to typical developments of unit b (Fig. 20, 24). Cores collected (78-118 in Fig. 26) suggest that unit c comprises sands and probably gravels overlain by thin cohesive laminated clays. Like unit b, it appears absent in the southern part of the survey area.

In the south, the uppermost acoustic unit d1 is acoustically transparent (Fig. 23), and is ponded in valleys and basins, only rarely onlapping at their margins, and reaches thicknesses of 20 ms. Over highs it rests unconformably on both units a and b, but appears conformable on unit c. It thins northwards, and in the Bull Rock channel it is rarely more than 3 ms thick (Fig. 24). Cores 78-112, -115, -118 and 77-15 (Fig. 26) show that at least the upper part of this unit comprises muds and silty muds of LaHave Clay. It is probable that the apparent absence of acoustic units b and c in the southern part of the area (Fig. 23) is due to a rapid southwards facies change in these units, so that the lower part of acoustic unit d1 is correlative with unit b and/or unit c.

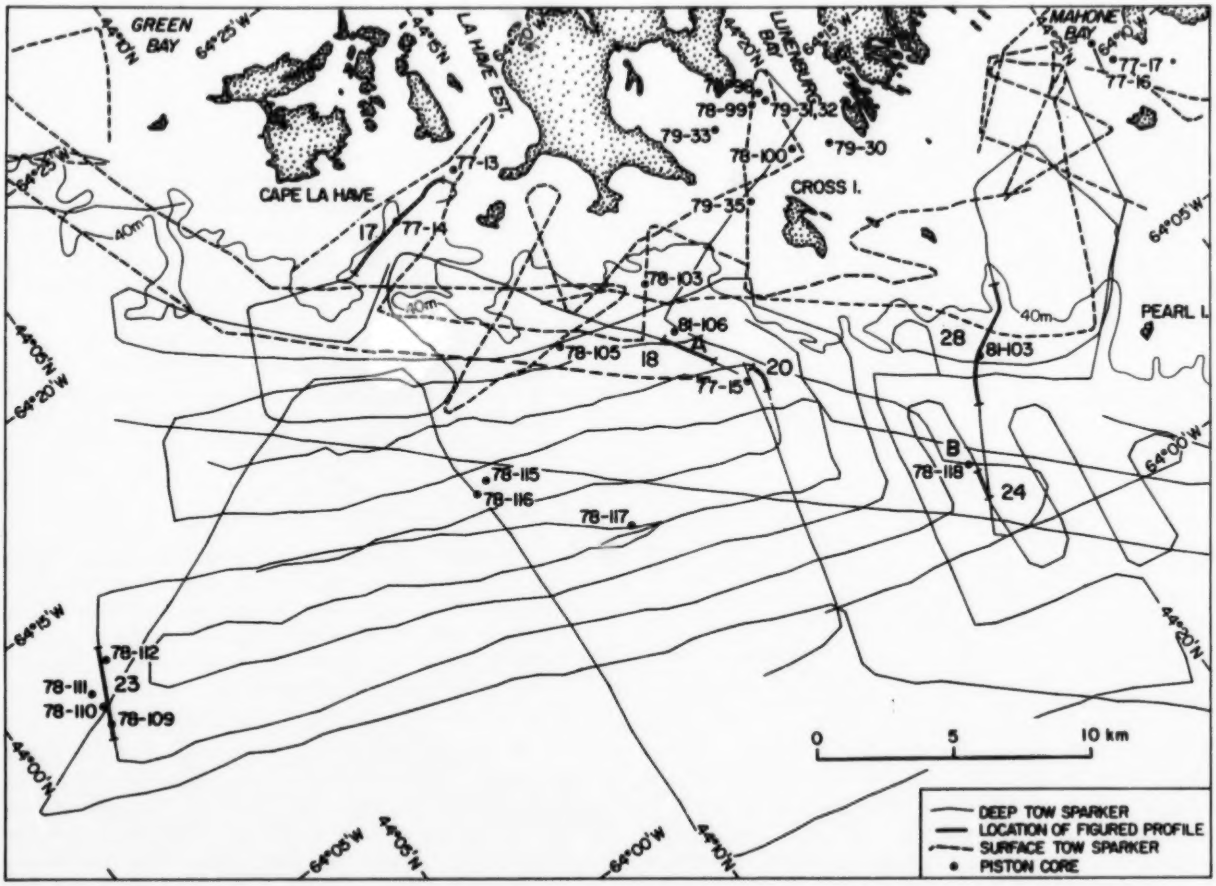

GREEN BAY
44°10'N
64°25'W
LA HAVE EST.
44°15'N
CAPE LA HAVE
77-13
17
77-14
40m
44°05'N
64°20'W
LUNENBURG BAY
44°20'N
64°15'W
78-98
78-99
79-31,32
79-33
78-100
79-30
CROSS I.
79-35
78-103
81-106
A
78-105
18
20
77-15
28
81-103
40m
PEARL I.
MAHONE BAY
64°10'W
77-17
77-16
64°05'W
64°00'W
B
78-118
24
78-115
78-116
78-117
64°15'W
78-112
78-111
23
78-110
78-109
44°00'N
64°05'W
44°05'N
64°00'W
44°10'N
44°20'N
0
5
10 km
DEEP TOW SPARKER
LOCATION OF FIGURED PROFILE
SURFACE TOW SPARKER
PISTON CORE

Figure 21. Location of seismic reflection profiles and cores in the area south of LaHave estuary-Mahone Bay; location of profiles illustrated in Figures 17, 18, 20, 23, 24 and 28 are shown. A and B are locations of large-volume grab samples.

On highs, acoustic units a and b are eroded to a prominent unconformity (Fig. 24) which in places is overlain by acoustic units c or d. The greatest depth of this unconformity is 122 m below sea level and decreases landwards (Fig. 25). The unconformity is remarkably planar (Fig. 25); except in water depths of less than 75 m, it does not appear to be irregularly channeled or scoured, even near steep bedrock slopes (Fig. 20, 23, 24).

LaHave estuary – Lunenburg Bay – outer Mahone Bay

At the northern edge of the detailed survey area south of Cross Island are the shallow inlets of LaHave estuary, Lunenburg Bay and the approaches to Mahone Bay. A systematic seismic survey is more difficult in this area because of hazards to navigation and multiples on the seismic records due to the shallow water. Nevertheless, the acoustic stratigraphy recognized farther south can be tentatively extended to this region.

The early till (T1) occurs discontinuously throughout the area resting on bedrock. Acoustic unit a overlies till or bedrock. It was not observed north of the outermost parts of Lunenburg Bay and LaHave estuary; it was not seen in water depths less than 58 m. About 7 km southwest of Pearl Island, unit a overlies stratified sediment.

Well stratified, ponded deposits equivalent to acoustic units b and c are widespread, and up to 40 ms thick. In some areas, an upper sequence (c) fills narrow channels that are cut into a more extensive stratified sequence (b), which is frequently wedge-shaped (Fig. 28). In many places, however, the two units are difficult to distinguish. About 5 km south of Cross Island, a ridge of till grades laterally into a wedge-shaped stratified sequence (Fig. 18) correlative with unit c, which in turn overlies units b and a. Other less clear lateral transitions from till to stratified sediment of acoustic unit b or c occur in LaHave estuary (Fig. 17) and at the approaches to Mahone Bay (Fig. 28). These tills are referred to as the "late till" unit (T2) (Fig. 29). Their maximum observed thickness is 20 ms. Like the early till (T1), they appear discontinuous and dissected, and their original morphology is uncertain. In a few localities, late till has been found overlying early till (Fig. 28).

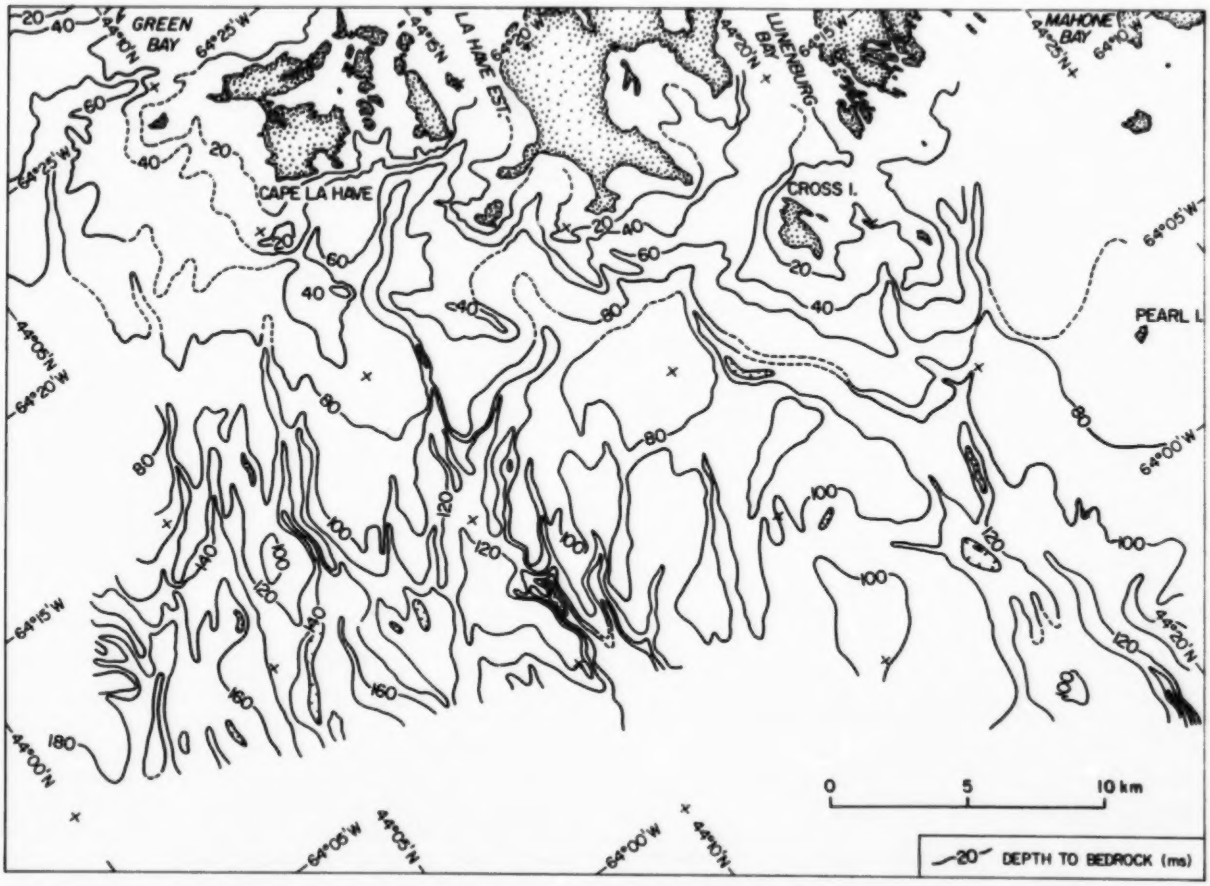


Figure 22. Depth to bedrock (milliseconds below present sea level at 20 ms intervals) in the area south of LaHave estuary-Mahone Bay.

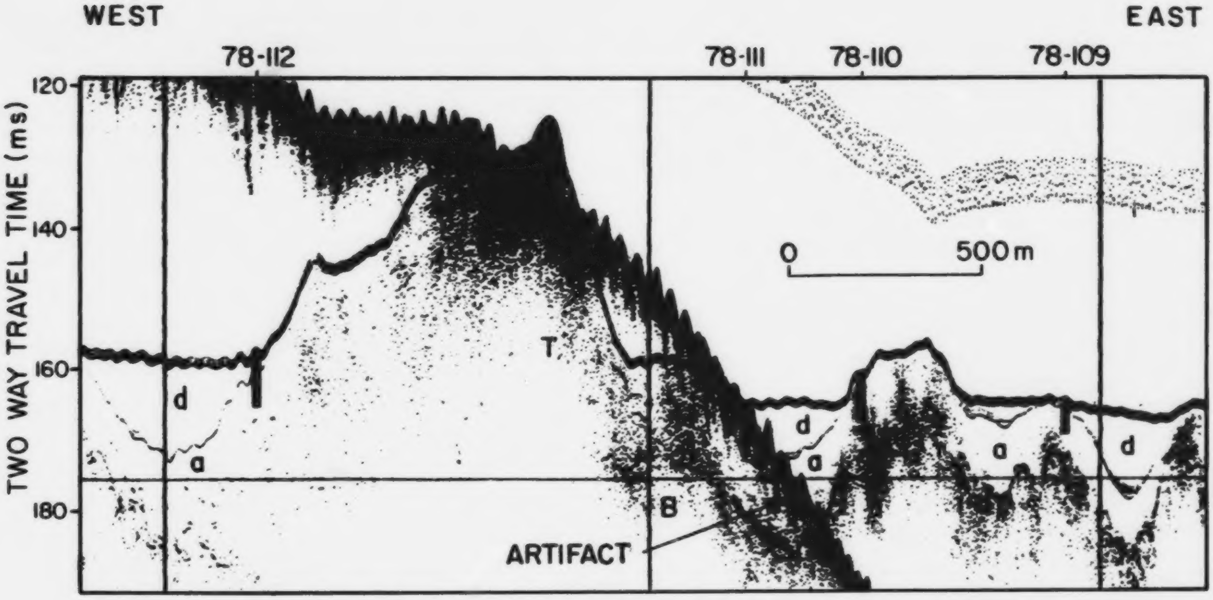


Figure 23. Seismic reflection profile through core sites 78-109 to 78-112 showing bedrock (B), till (T) and acoustic units a and d. Location shown in Figure 21.

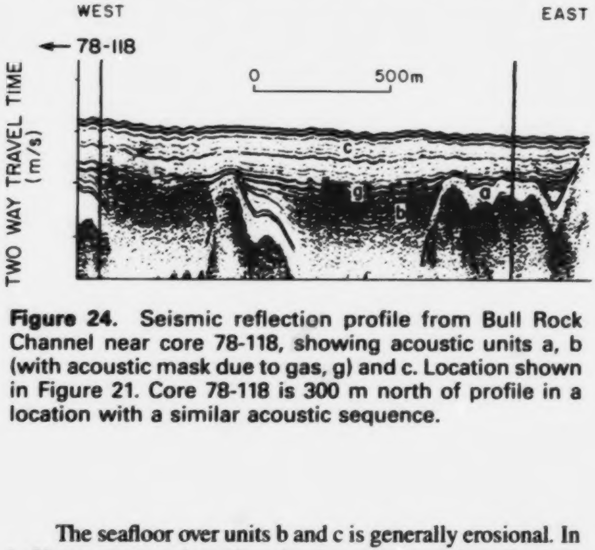


Figure 24. Seismic reflection profile from Bull Rock Channel near core 78-118, showing acoustic units a, b (with acoustic mask due to gas, g) and c. Location shown in Figure 21. Core 78-118 is 300 m north of profile in a location with a similar acoustic sequence.

The seafloor over units b and c is generally erosional. In LaHave estuary, where there has been deep erosion of units b or c, sand and gravel have been recovered in cores 77-13 and 77-14 (Fig. 26). In Lunenburg Bay and near Cross Island, in areas where there is little evidence of sea floor erosion, the upper part of unit c has been penetrated by cores 81-103 and 81-106 (Fig. 26) and comprises cohesive mud with silty or sandy laminae.

Mahone Bay

The acoustic stratigraphy of Mahone Bay was described by Barnes and Piper (1978). In the southern part of the bay, a finely stratified but very transparent unit up to 75 ms thick rests directly on till. It was called the Mahone Bay unit, and was interpreted as finely stratified proglacial silts and muds. This unit has not been cored, but bedrock morphology of Mahone Bay suggests it is probably lacustrine in origin (Barnes and Piper, 1978). The finely stratified Mahone Bay unit is overlain by non-stratified transparent sediment, frequently with acoustic masks due to gas (Keen and Piper, 1976), which is at least 10 ms thick in places. This sediment was equated by Barnes and Piper (1978) with LaHave Clay, and is here termed acoustic unit d1.

St. Margaret's Bay

The acoustic stratigraphy of St. Margaret's Bay was described by Piper and Keen (1976). Overlying the till is finely stratified sediment up to 30 ms thick, which Piper and Keen compared with the Emerald Silt and which is here correlated with acoustic unit c. It partly onlaps and drapes basin margins. It is overlain (in some areas unconformably) by transparent sediment with acoustic masks, up to 15 ms thick, termed acoustic unit d1.

Port Mouton – Liverpool Bay area

Most acoustic data in this area (Fig. 30) are 3.5 kHz profiles (Fig. 19). Transparent stratified sediment of acoustic unit c, up to 20 ms thick, occurs in valleys and basins. It is overlain, in places unconformably, by up to 10 ms of reflective surface sediment, consisting of sands. In Port Mouton and inner Liverpool Bay, these surface sands pass laterally into thicker, more transparent sediments with gas masks, assigned to unit d1. The sands are termed acoustic unit d2 and correspond to the sand facies of the Sable Island Sand and Gravel of King (1970).

Summary

In the area south of Cross Island, four main acoustic stratigraphic units overlie a widespread dissected till unit. termed the early till:

unit a –	a transparent draped acoustic unit comprising cohesive laminated clays passing down into sands and gravels;
unit b –	a well stratified acoustic unit, which thins rapidly southwards, and probably consists of sands and gravels;
unit c –	a ponded stratified unit that rests unconformably on units a and b. It comprises cohesive laminated clays passing down into sands and gravels;
unit d –	a ponded acoustically transparent unit of muds, for the most part equated with LaHave Clay (King, 1970).

Acoustic units a, b, c and possibly the lower part of d offshore can be equated with the Emerald Silt of King (1970) and Drapeau and King (1972).

Closer to the coast, in the approaches to Mahone Bay and the LaHave estuary, well stratified acoustic sequences equated with units b and c overlie, and locally interfinger with, the late till unit (Fig. 18, 28).

In coastal bays (Port Mouton, Liverpool Bay, Lunenburg Bay, Mahone Bay and St. Margaret's Bay), thick, finely stratified acoustic sequences, which are generally equivalent to the fine upper part of unit c offshore, underlie a transparent surficial acoustic unit d1. In more exposed areas, the surficial acoustic unit d2 comprises ponded sediments with strong surface reflectivity, and poor stratification; these sediments are correlated with Sable Island Sand and Gravel (King, 1970).

There is a planar unconformity above units a and b which is approximately correlative with the late till unit. In an

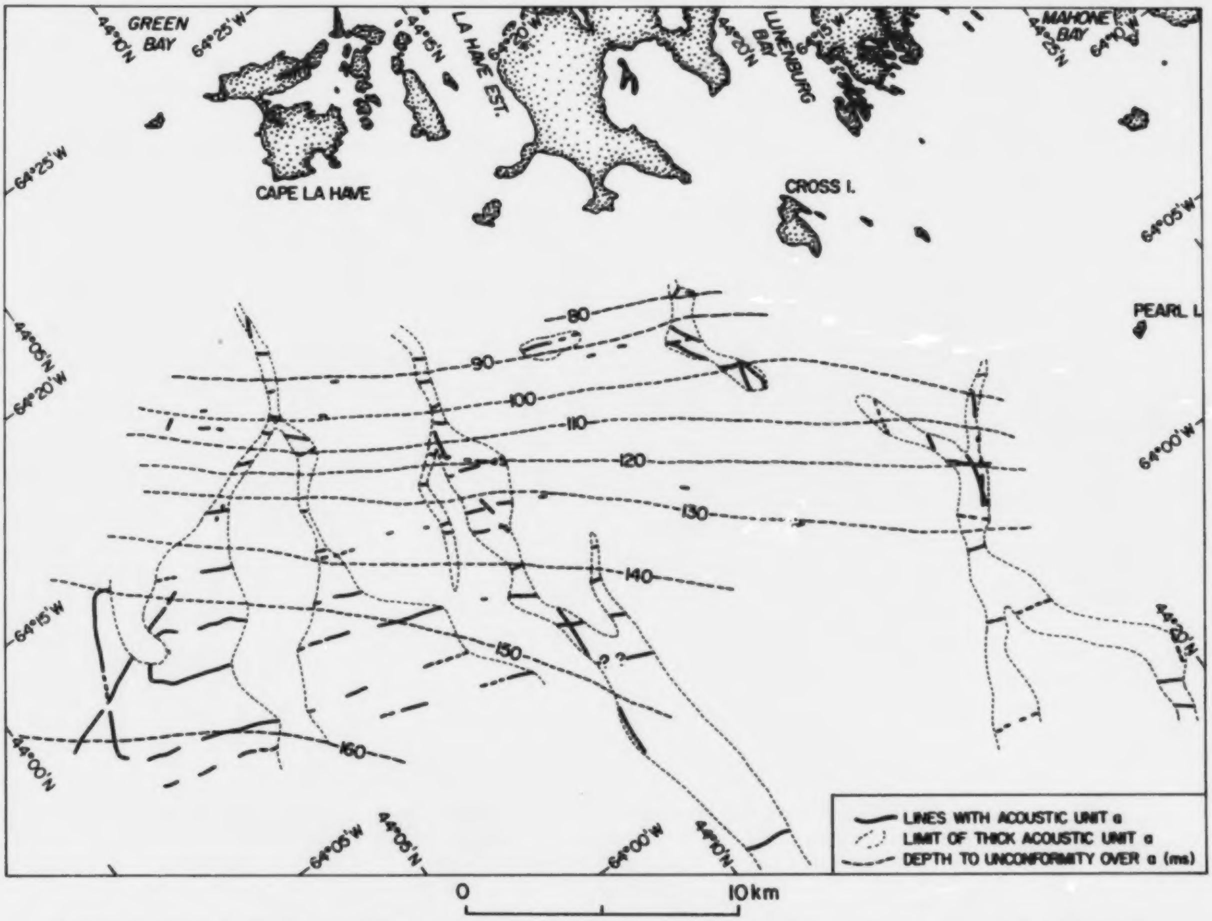
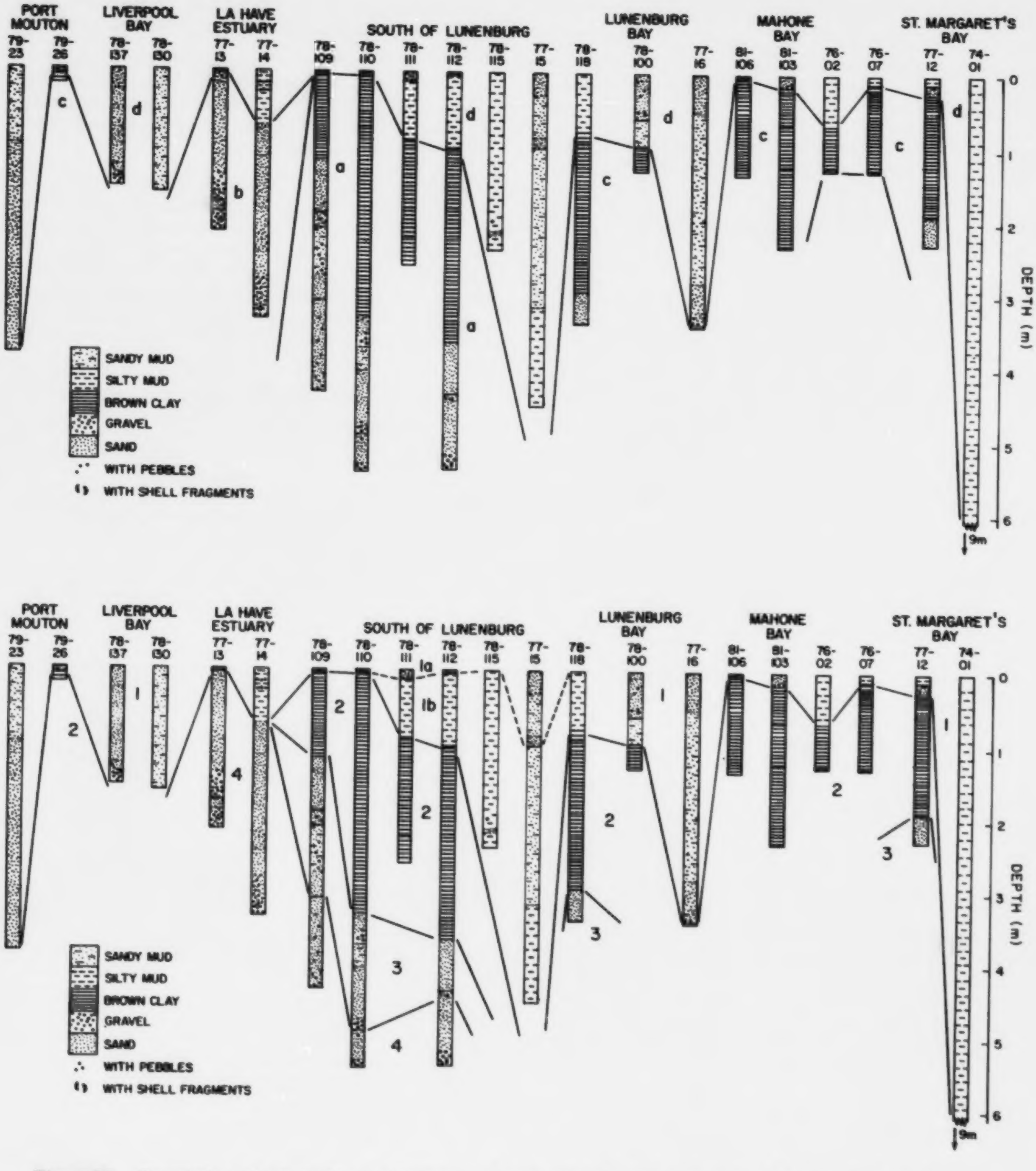

GREEN BAY
44°10'N
64°25'W
44°15'N
LA HAVE EST.
64°20'W
44°20'N
LUNENBURG BAY
64°15'W
MAHONE BAY
44°25'N
64°10'W
64°25'W
CAPE LA HAVE
CROSS I.
64°05'W
PEARL I.
64°00'W
44°05'N
64°20'W
80
90
100
110
120
130
140
150
160
64°15'W
44°20'N
44°00'N
64°05'W
44°05'N
64°00'W
44°10'N
LINES WITH ACOUSTIC UNIT a
LIMIT OF THICK ACOUSTIC UNIT a
DEPTH TO UNCONFORMITY OVER a (ms)
0
10km

Figure 25. Distribution of acoustic unit a in area south of LaHave estuary-Mahone Bay, and generalized structure contour map of unconformity developed above unit a (in milliseconds below present sea level). Note 1 ms = 0.75 m water depth.



PORT MOUTON
79-23
79-26
LIVERPOOL BAY
78-137
78-130
LA HAVE ESTUARY
77-13
77-14
SOUTH OF LUNENBURG
78-109
78-110
78-111
78-112
78-115
77-15
78-118
LUNENBURG BAY
78-100
77-16
MAHONE BAY
81-106
81-103
76-02
76-07
ST. MARGARET'S BAY
77-12
74-01
a
b
c
d
DEPTH (m)
0
1
2
3
4
5
6
9m
SANDY MUD
SILTY MUD
BROWN CLAY
GRAVEL
SAND
WITH PEBBLES
WITH SHELL FRAGMENTS
Ia
Ib
1
2
3
4

Figure 26. Correlation of selected long piston cores showing (a) acoustic units a-d and (b) lithofacies 1-4. Core locations are shown in Figures 21 and 27. For discussion of acoustic units and lithofacies, see text.

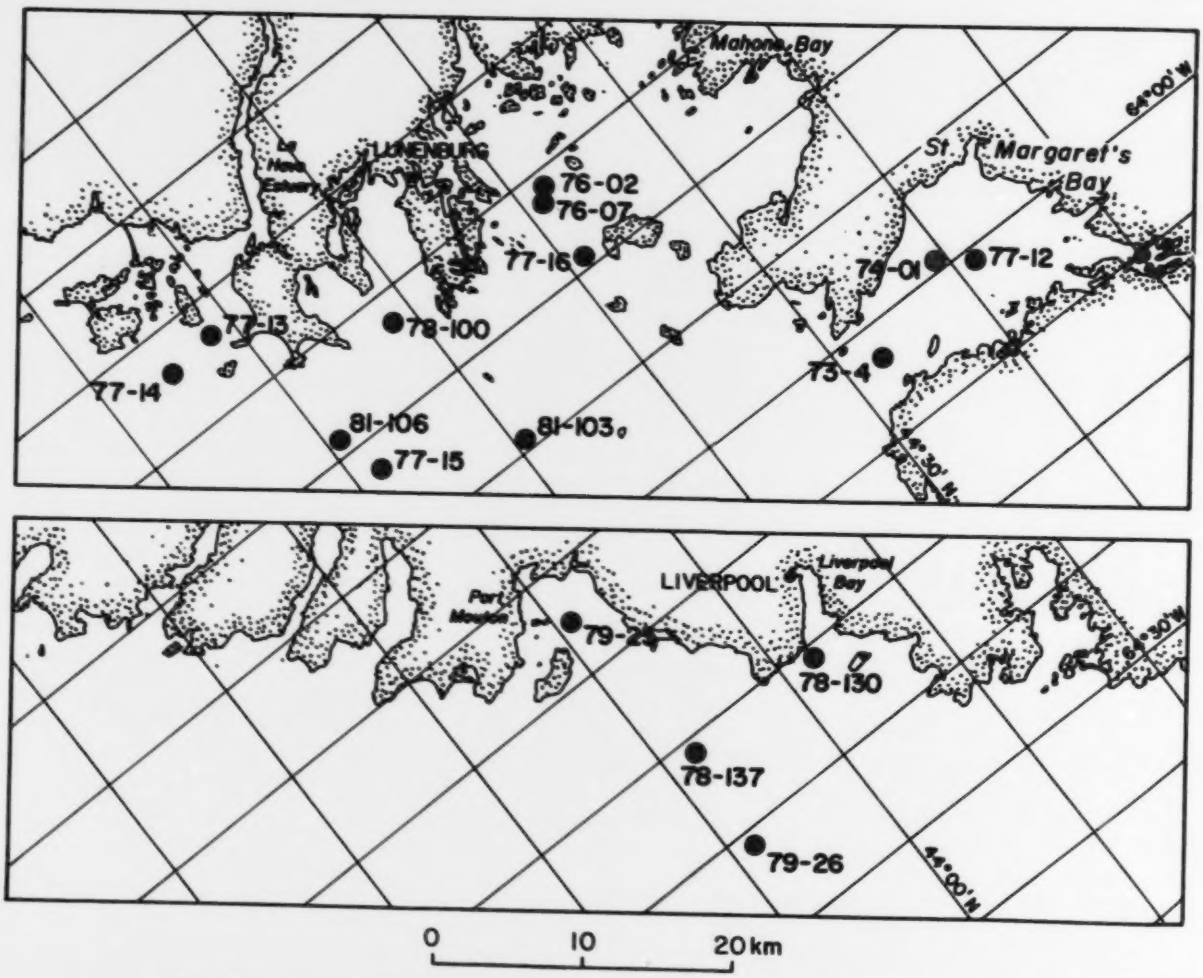

Mahone Bay
64°00'W
LUNENBURG
La Have Estuary
76-02
76-07
St. Margaret's Bay
77-16
74-01
77-12
77-13
78-100
77-14
73-4
81-106
81-103
77-15
44°30'N
LIVERPOOL
Liverpool Bay
Port Mouton
79-24
64°30'W
78-130
78-137
79-26
44°00'N
0
10
20km

Figure 27. Location of piston cores used in this study and illustrated in Figure 26.

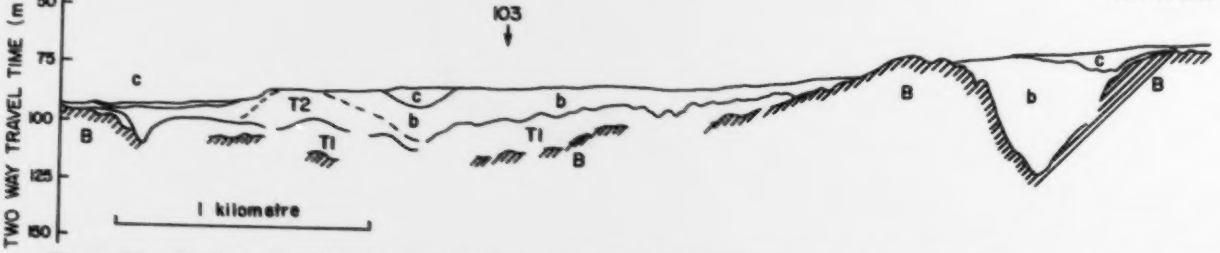

Southeast
Northwest
TWO WAY TRAVEL TIME (ms)
50
75
100
125
150
103
c
T2
T1
B
b
1 kilometre

Figure 28. Shallow towed v-fin seismic reflection profile and interpretative line drawing, Bull Rock Channel, south of Mahone Bay. Bedrock (B) is overlain by early till (T1) and late till (T2), which interfingers with acoustic unit b. Channels cut in unit b are filled by acoustic unit c. Number 103 indicates location of core 81-103. Location shown in Figure 21.

area of such rough topography this planar truncation surface is difficult to explain except as a nearshore wave-cut platform resulting from a lowered stand of sea level. Only in depths of less than 75 m is the unconformity channelled, and here it is probably subaerial in origin.

Distribution and character of till

In the area south of Cross Island, the distribution of till has been mapped using seismic data with a 2 km line spacing. A widespread but discontinuous "early till" unit (Fig. 29), rarely more than a few milliseconds thick, extends all the way to the Pennant Point moraine (Drapeau and King, 1972). Near the coastline, this early till is overlain by the "late till" unit. In other parts of the South Shore, seismic coverage is less dense. The late till has not been recognized outside the LeHave estuary-Mahone Bay area. Discontinuous early tills are widespread off Green Bay and Liverpool Bay, but otherwise till is rare offshore in water depths of less than 120 m, as shown in Figure 31 and by Parrott et al. (1980).

In St. Margaret's and Mahone bays (and a few other sheltered coastal areas), till is widespread and drumlins can be recognized both from seismic reflection profiles and sea floor morphology. King (1980) has shown that the discontinuous distribution of till in the offshore areas is the result of coastal erosion during the Holocene transgression.

In many areas, where little or no erosion has occurred, there is a relatively featureless till sheet usually less than 7 ms thick. In the eastern part of the South Shore, drumlinoid mounds of till are common and reach thicknesses as great as 60 ms. In protected areas (such as St. Margaret's and Mahone bays) these drumlins rise tens of metres above the surrounding sediment, and may emerge as islands. In more exposed waters (e.g. Lunenburg Bay and approaches), although drumlins are abundant on land, the till surface has been planed off by marine erosion and well defined drumlinoid forms are rare.

In some shallow water areas, it is difficult to distinguish till from bedrock using seismic reflection profiles, especially where the till is thin or deeply buried beneath younger sediments. It is uncertain whether there is any till nearshore between Medway Harbour and Green Bay or how extensive the till is in Liverpool and inner Lunenburg bays.

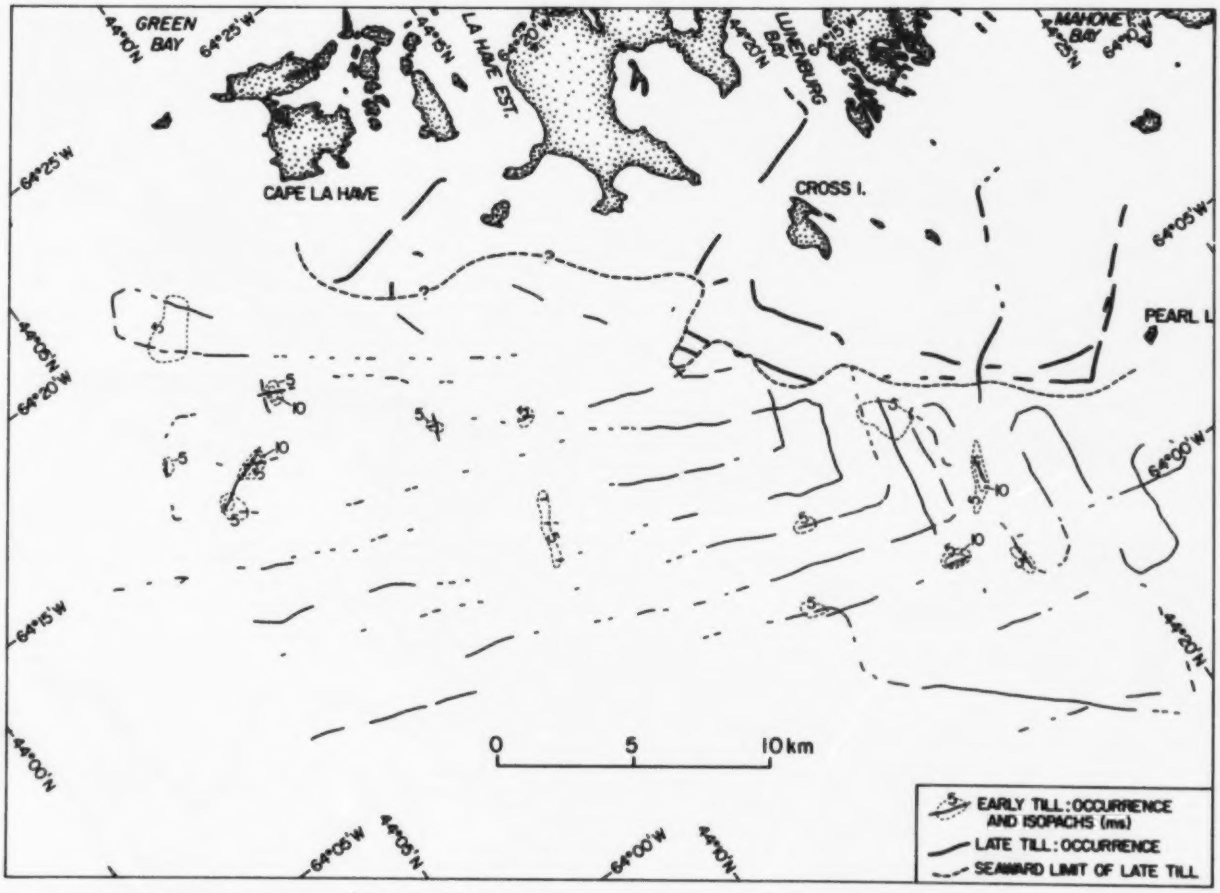

GREEN BAY
64°25'W
44°10'N
44°15'N
LA HAVE EST.
64°20'W
44°20'N
LUNENBURG BAY
MAHONE BAY
64°10'W
64°25'W
CAPE LA HAVE
CROSS I.
64°05'W
PEARL I.
44°05'N
64°20'W
64°00'W
64°15'W
44°20'N
44°00'N
64°05'W
44°05'N
64°00'W
44°10'N
5
10
0
5
10 km
EARLY TILL: OCCURRENCE AND ISOPACHS (ms)
LATE TILL: OCCURRENCE
SEAWARD LIMIT OF LATE TILL

Figure 29. Distribution of early and late tills along seismic reflection profile tracks south of LaHave estuary-Mahone Bay. (Compare with Figure 21). Early till is less than 5 ms thick except where shown as thicker by isopachs.

Till petrology, however, can be inferred from the lithology of lag gravels where till is exposed on the sea floor. In general, the petrology of nearshore gravels is found to be a reliable indicator of the petrology of a parent till. Piper and Keen (1976) used short drill cores from St. Margaret's Bay to infer till petrology. Gravel petrology between St. Margaret's Bay and LaHave estuary suggests that red drumlinoid till with far-travelled clasts predominats. Locally derived tills include granitic till found in parts of St. Margaret's Bay (Piper and Keen, 1976), and slaty till scattered throughout Lunenburg Bay and approaches (Fig. 32).

Large volume (ca. 1 m^3) grab samples were taken from exposures of late and early tills south of Cross Island (A to B, respectively, Fig. 21). Muddy sandy gravels were recovered which represent some marine reworking of the parent till. The late till comprised more than 97% Meguma clasts, principally slate, with rare granite; gravel from this till resembles gravel type B (Fig. 32). The early till had a more varied lithological composition, with about 10% non-Meguma lithologies, including red rhyolites and basalt characteristic of the red Lawrencetown till; gravel from early till resembles gravel type C (Fig. 32). On the basis of only two samples, however, it is not possible to generalize on the regional lithological character of the two tills.

Between the LaHave estuary and Port Mouton few data exist on gravel petrology, but no far-travelled clasts have been found, suggesting that most of the till is of local origin. From Port Mouton to Lockeport, granite pebbles predominate in marine gravels, even in areas of Meguma bedrock (Fig. 33). The closest granite "upstream" from the area west of Sable River is in the main South Mountain pluton at Kejimkujik, suggesting long distant transport of till. Nolan (1963) found high concentrations of augite on some beaches in this region, and heavy mineral assemblages are also locally rich in augite; this mineral is derived principally from the North Mountain Basalt.

Piston core sediments

Lithostratigraphy

About 60 piston cores have been attempted in the study area; of these, some 20 penetrated sediment markedly different from that accumulating at present (Fig. 26). Four lithofacies were identified, numbered from the top downwards.

Facies 1 consists of lithofacies with textural and acoustical features similar to those characterizing LaHave Clay, Sable Island Sand and Gravel and intermediates (see King, 1967, 1970; Parrott et al., 1980) and corresponds to acoustic units d1 and d2. These lithologies are similar to sediments presently accumulating in various areas of the South Shore. The LaHave Clay is a bioturbated olive grey organic-rich silty clay, whereas the Sable Island Sand and Gravel is a well sorted marine sand; intermediates between the two include grey, biogenic silts and sandy muds. In offshore areas of the South Shore, the lower part (facies 1b) is commonly much finer grained than the surface sediments (facies 1a).

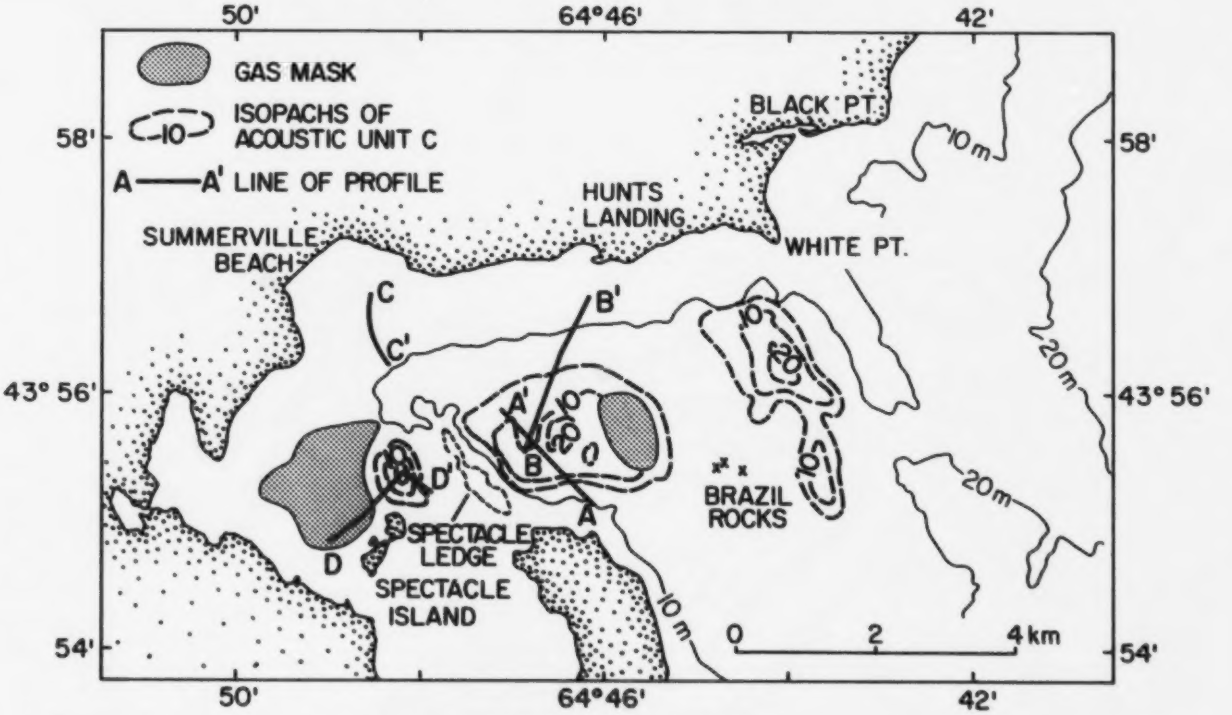


Figure 30. Bathymetry (in metres), isopachs of acoustic unit c (in milliseconds two-way travel time), and distribution of acoustic masks due to gas, Port Mouton area. Profiles are shown in Figure 19.

Facies 2 consists of laminated brown cohesive (sticky) clays or clayey muds. Many have thin black (pyritic) bands or silty layers and scattered granules or gravel. They contain sparse marine or estuarine microfossils. In many respects, this lithology resembles the Emerald Silt of King (1970). It corresponds to the upper part of acoustic unit c, and to acoustic unit a.

Facies 3 consists of generally poorly fossiliferous marine sands and gravels underlying facies 2.

Facies 4 consists of gravels and sands that lack marine fossils. Facies 3 and 4 underlie facies 2 at the base of acoustic units a and c. In addition, facies 4 occurs in acoustic unit b. Facies 3 and 4 cannot be distinguished acoustically in seismic records.

In most cores, facies 1 overlies facies 2, which in turn overlies facies 3 and 4. However, there is not a simple correspondence between facies and acoustic units. There is a repetition of facies, so that the fining up sequence of marine facies 3 to 2 occurs both in acoustic unit a and in the younger acoustic unit c.

Sedimentology

Grain size distribution and sedimentary structures in facies 1 are described in the section on Surficial Sediments. The interpretation of facies 2, 3 and 4 is based partly on grain-size studies of cores 77-12 and 78-112 and partly on acoustically and sedimentologically similar sediments from Kaipokok Bay, Labrador (Kontopoulos and Piper, 1982).

The sediments of facies 2 are brown cohesive clays with thin pyritic bands and fine silt laminae. Some contain scattered granules and gravel, which are presumably ice-rafted. There is a pronounced downward coarsening in facies 2, with a gradual increase in sand, until the facies passes into facies 3 (Fig. 34, 35).

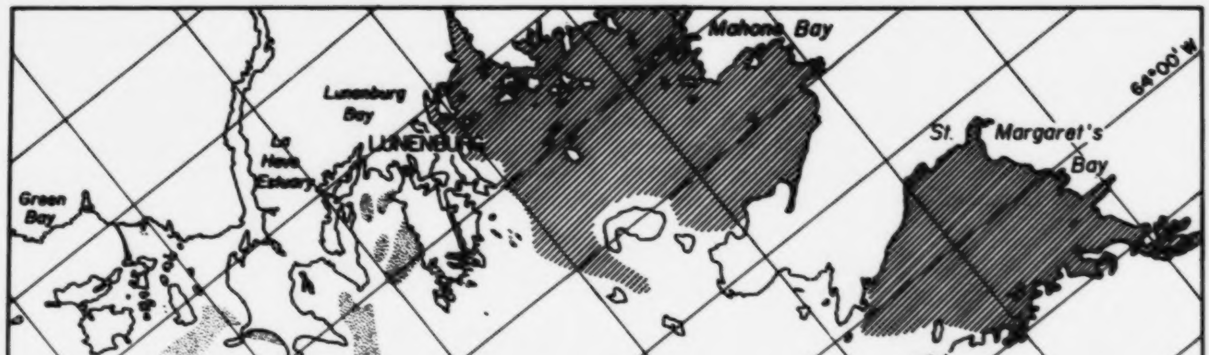


Figure 31. Distribution of till, South Shore. Hachured pattern indicates extensive areas of till in nearshore bays; stipple indicates eroded remnants of till on open continental shelf.

In most nearshore cores, bulk grain size distribution and clay mineralogy in facies 2 are not significantly different from facies 1. Sediment colour suggests facies 2 accumulated under less severely reducing bottom conditions, and bioturbation is considerably less. In the offshore cores, facies 2 is commonly finer grained than facies 1 (Fig. 34), lacks bioturbation, and thus appears to represent different sedimentation conditions.

In facies 1, the silty muds commonly occur in graded beds 3-15 cm thick. These beds have sharp silt-rich bases, and grade finer upwards. They have been described in detail by Letson (1980), and Piper et al. (1983) ascribed their origin to resuspension and deposition of sediment during rare large storms. The silty bases of the beds commonly show faint internal lamination, which is sometimes lenticular (cores 78-118, 78-112a, in Fig. 36).

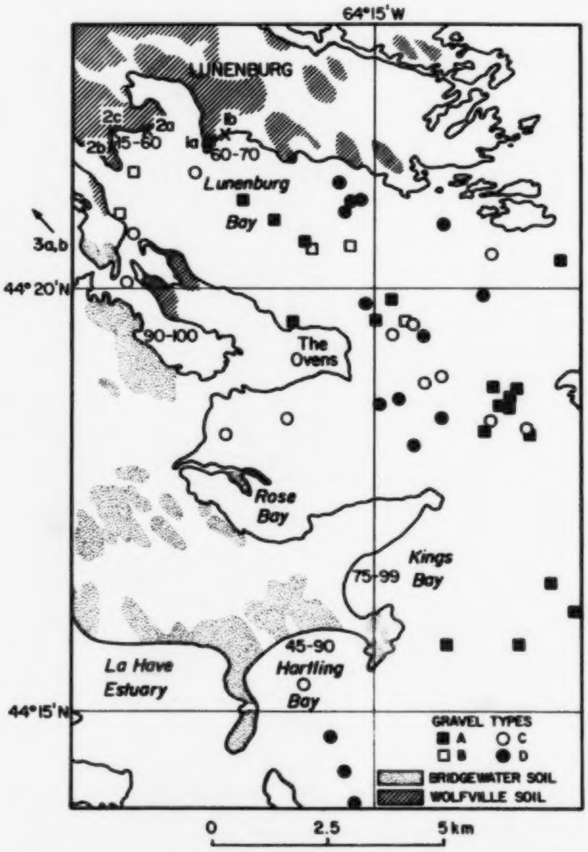

64°15'W
LUNENBURG
2c
2a
2b
15-60
1b
1a
60-70
Lunenburg Bay
3a,b
44°20'N
90-100
The Ovens
Rose Bay
Kings Bay
75-99
45-90
Hartling Bay
La Have Estuary
44°15'N
GRAVEL TYPES
■ A
○ C
□ B
● D
BRIDGEWATER SOIL
WOLFVILLE SOIL
0
2.5
5km

Figure 32. Petrology of gravel samples, Lunenburg Bay. A: slate only; B: slate and Meguma sandstone; C: slate, Meguma sandstone, rare exotic clasts; D: principally exotic clasts. Soil types on land from Cann and Hilchey (1958): Wolfville soil = red till drumlins (Lawrencetown till); Bridgewater soil = slaty drumlins. Numbers are percent Meguma lithologies in tills. Numbers 1a-3b refer to till and beach samplos illustrated in Figure 54.

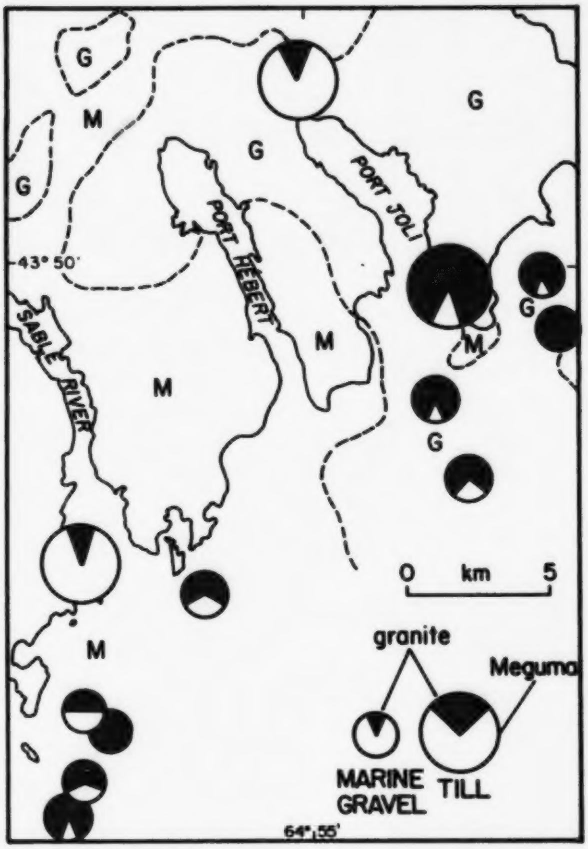

G
M
G
G
G
PORT JOLI
PORT HEBERT
43°50'
SABLE RIVER
M
M
G
M
G
M
0 km 5
granite
Meguma
MARINE GRAVEL
TILL
64°55'

Figure 33. Petrology of tills on land and marine gravels, Port Hebert region. Land geology after Taylor (1967). M = Meguma Group; G = granite. Geological boundaries shown by dashed lines.

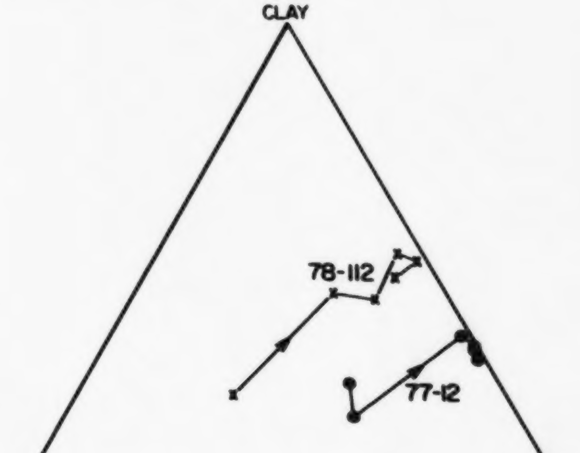


Figure 34. Grain size analyses of series of samples from sediment facies 2, showing up-core decrease in sand content.

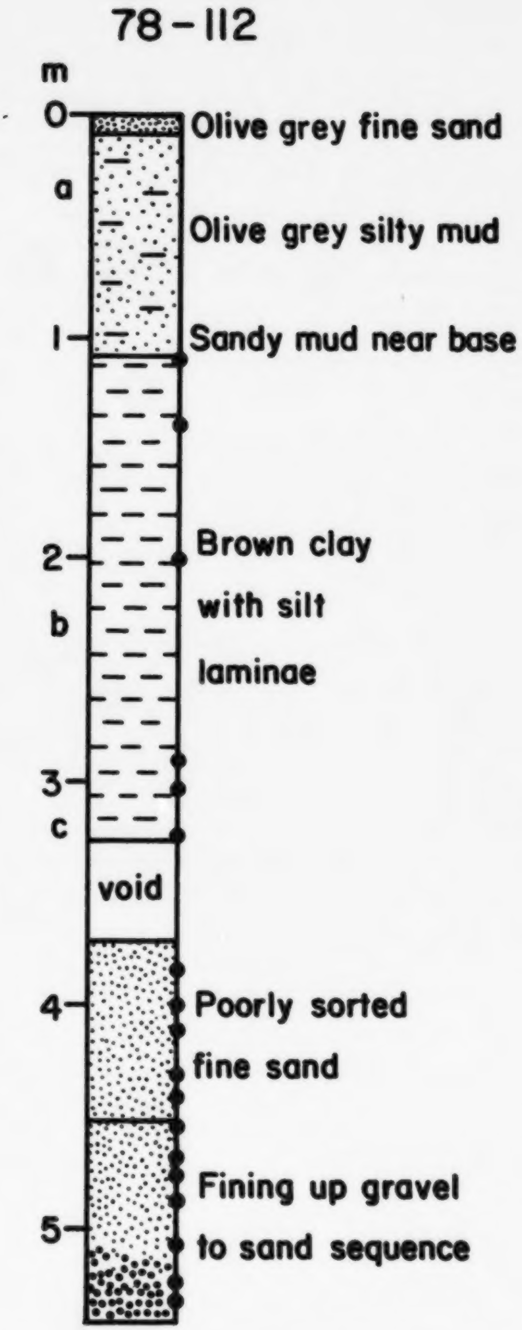


Figure 35. Lithostratigraphy of core 78-112; a, b, c indicate x-radiographs in Figure 36; dots indicate location of samples for size analyses shown in Figures 34 and 37.

Facies 2 only rarely contains graded beds (core 78-112b, c, Fig. 36). Changes in grain size between laminae or thin beds are commonly abrupt, and silty units lack internal lamination. At some stratigraphic levels, dispersed clasts are common. Laminae in facies 2 resemble those described by Kontopoulos and Piper (1982) from units C and D in Kaipokok Bay, Labrador; they intepreted the laminae to be due to discharge variations in suspended sediment close to an ice margin, perhaps similar to processes described by Elverhoi et al. (1980). Further work is necessary on South Shore sediments to substantiate such an interpretation.

The sands and gravels from facies 3 and 4 differ from those of surficial sediments in their grain size distributions and have a large fine tail. Similar features were found in proglacial sands in Kaipokok Bay by Kontopoulos and Piper (1982).

Piston core biostratigraphy

Introduction

Nine cores, which represent the range of sediments sampled, are described in detail below. Foraminifera have been counted from approximately 50 samples by D.B. Scott (personal communications, 1976-78). Interpretation of these data suggest depositional environments, based on living foraminifera distributions mapped by Bartlett (1964), Gregory (1970), Scott (1977), Scott et al. (1977), Schafer and Cole (1978), Scott and Medioli (1980a) and Scott et al. (1980). Palynomorphs have been studied in selected cores or core sections. Most data were presented by Mudie (1980); the remainder are reported in Tables 2 and 3. Pollen and spore assemblages are used for approximate dating of the marine sediments by relating the marine samples to ^{14}C-dated palynostratigraphies reported for onshore lacustrine sediments by Livingstone (1968), Railton (1973), and Green (1976). Radiocarbon dates (Table 1) from suitable material in the marine sediments provide additional age control. Dinoflagellate cyst (dinocyst) assemblages provide paleoecological information on surface water conditions at the time of sediment deposition, thereby compensating for the absence or low numbers of planktonic foraminifera found in coastal waters. The dinocyst assemblages are interpreted on the basis of distribution data described by Mudie (1980, 1981; Miller et al., 1982; Mudie and Short, 1983; Vilks and Mudie, 1983). The main indicator dinoflagellate cyst species are illustrated in Miller et al. (1982) and Mudie and Short (1983).

Core 74-1

This core is from a water depth of 75 m in the central basin of St.Margaret's Bay. It appears to be entirely from acoustic unit d, but an acoustic mask due to gas prevents resolution of the sediment underlying the top 2 m. The

Table 1. ^{14}C dates from marine samples

Core No. (complete number)	Depth in Core (cm)	Water Depth (m)	Material Dated	Laboratory No.	Age (BP)
74-1 (74-021-1)	630	75	total organic C in mud	I-8353	3 970 ± 260
Hirtles Beach		3.1 below HWM	HWM peat	I-9930	785 ± 80
77-15 (77-002-15)	400-425	66	total organic C in mud	I-10467	14 000 ± 200
77-16 (77-002-16)	294-353	37	shells	GX-5736	4 140 ± 185
510-74-54	(grab sample)	14	eutrophic sapropel	GSC-2128	4 170 ± 80
78-137 (78-005-137)	143	44	shells (*Mya truncata*)	GX-5809	5 090 ± 190
77-14 (77-002-14)	58-61	35	total organic C in mud	GX-7633	10 985 ± 280

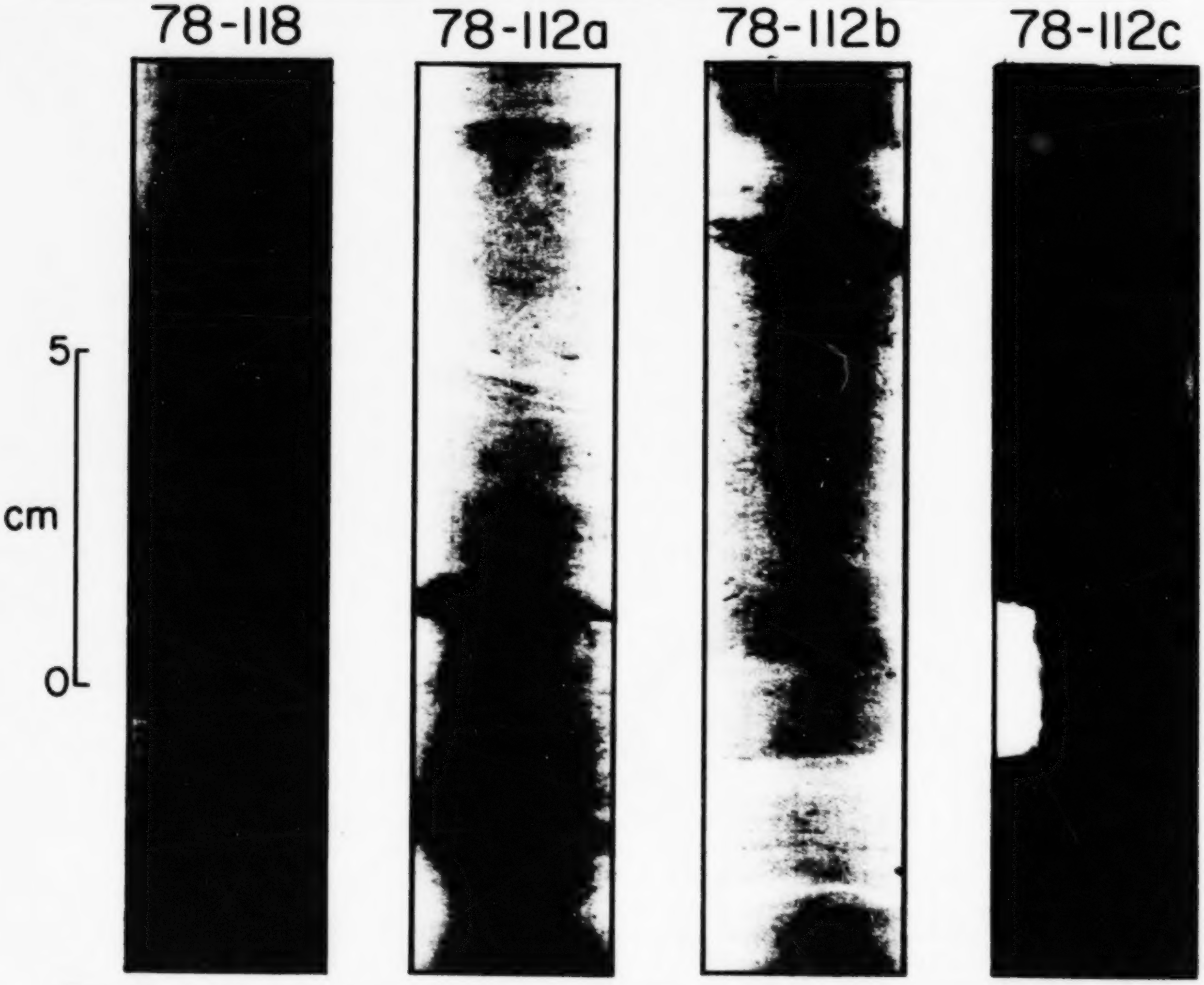


Figure 36. X-radiographs of laminae from cores 78-118 and 78-112. Locations for 78-112 shown in Figure 35. X-radiograph in 78-118 is at 60 cm depth. For explanation, see text.

textural characteristics and organic chemistry of the sediment in core 74-1 (Fig. 38) have been described in detail by Keen and Piper (1976) and Piper and Keen (1976); foraminifera data (Laidler, 1976) and palynomorph data are summarized in Figures 38 and 39 respectively.

The entire core (900 cm) comprises olive grey organic-rich mud (facies la) with abundant shell fragments and diatoms. The sediment appears bioturbated but x-radiography reveals indistinct silty laminae. In addition, there are two prominent thin layers of silt in the lower half of the core.

Four Quaternary pollen and spore assemblage zones can be delineated (Fig. 39) which correspond to the palynofacies described for lakes along the Atlantic coast of Nova Scotia by Livingstone and Livingstone (1958) and Livingstone (1968). The pollen zones in core 74-1 indicate that sediment below 525 cm was deposited during the *Tsuga* pollen maximum (pollen zone C2) which represents Holocene hypsithermal climatic interval. A continuous sequence of younger sediments is represented by pollen zones in the overlying sediment which represent the later Holocene climatic deterioration (zones C3a and C3b) and the most recent interval of historical changes in land use (zone C3c). A radiocarbon date of 3970 ± 260 BP for total organic carbon at 625 cm core depth (Piper and Keen, 1976) is in close agreement with the date of 3500-4000 BP assigned to the upper boundary of pollen zone C2 in southeastern Canada (Railton, 1973).

Foraminiferan numbers (total specimens per gram dry weight) are very low (2-32) for most sample intervals in core 74-1 and the assemblages comprise a low diversity of benthonic species. The species in samples above 562 cm core depth indicate an open bay environment with predominantly cold water species, whereas the assemblage between 552 and 562 cm closely resembles that presently found below the warm saline bottom water layer in Emerald Basin on the Scotian Shelf (Vilks and Rashid, 1976).

Table 2. Relative abundance of pollen and spores in core samples.

Core No.	76-04-2	77-002-14			78-05-100				78-05-112				77-002-15	
Sample Depth (cm)	120 cm	65 cm	475 cm	500 cm	60 cm	95 cm	100 cm	125 cm	25 cm	85 cm	101 cm	140 cm	475 cm	500 cm
Taxon														
Abies	1	1		1	1	2			2	3		2		7
Acer	1		3		4	5			1	3		+		
Alnus		5	8	5	2							1	13	3
Ambrosia			1		1									
Betula	8	27	8	27	11	3			1	4		3	13	14
Carpinus-Ostrya		+	1	2						1			2	7
Celtis		1												
Chenopodiaceae	2								1					
Cornus			1						1					
Corylus		1		3								+		3
Compositae	2	2						+	1				2	
Cyperaceae	2	2	2	2	1					2		+	2	7
Dryas	1		5	1								+		
Ericales	2	2	2	2	1							1		3
Fagus	1			1	1				1					3
Gramineae		3	4	1		2							2	
Lycopodium		3	3	2	3	2			1	1	13	2		
Myrica		2	1	1									2	3
Picea	24	16	15	18	35	35		+	59	51	50	65	6	14
Pinus	23	5	6	9	20	10		+	19	16	13	11	6	14
Polypodiaceae	10	15		6	2	2			1		13	2	3	3
Ptericium	1	3	4		2	2			1			+		
Quercus	2	+	8	1	3	2				1		2	8	
Rosaceae	1	+	4	5								3		
Salix	4	3	4	3								1		
Saxifraga	1	+		1										
Selaginella		3		1								+		3
Sphagnum	3	5		2	1	2			+	2	13			
Tsuga	1	+			16	33			14	11		+	5	
Varia	5	7	3	4	1	33			1	3		2		
NAP (% Total)	33	42	23	24	12	12			4	8	25	12	34	33
Pre-Quaternary	49	17	12	12	22	15	100		21	24	82	15	11	17
Total Counted	200	200	200	200	200	120	6	3	214	228	8	185	100	100
Number per gram	2100	2200	3100	7300	12,900	3800		76	13,400	7900	310	3600	9460	7330

+ present in slide, but <0.5%.

In contrast to the foraminifera, dinocyst numbers and species diversity are high throughout Core 74-1. Three dinocyst species assemblages are evident (Fig. 39), as summarized below.

1. *Operculodinium centrocarpum – Bitectatodinium tepikiense* (0-150 cm): this cyst assemblage characterizes the most recent sediments in sheltered bays with near-normal marine salinities along the Atlantic coast of central Nova Scotia to southern Maine (Mudie, 1980; Miller et al., 1982). In St. Margaret's Bay, the presence of *Multispinula minuta* may indicate a recent increase in the inflow of relatively cold inner shelf water.

2. *Peridinium conicoides – O. centrocarpum* (150-500 cm): this assemblage is similar to that characterizing the modern sediments of the central Scotian Shelf which are overlain by a surface layer of warm water. In core 74-1, however, a relatively strong fluvial influence is indicated by the presence of significant numbers of *Gonyaulax tamarensis* cysts, Dinocyst species C and freshwater cysts, including *Peridinium* Cyst C (Norris and McAndrews, 1970) and *Micrhystridium* species F (Mudie, 1980). *P. conicoides* in this paper refers to cysts of *Protoperidinium conicoides* and closely allied taxa which produce cysts resembling *Brigantedinium simplex* (Wall) Reid.

3. *O. centrocarpum – Spiniferites* spp. (500-750 cm): this assemblage is similar to that characterizing open bays with relatively warm (>15°C), saline summer surface water, such as is presently found in the southern Gulf of St. Lawrence and near Cape Cod. The predominance of Gonyaulacean cyst taxa suggests warmer than present surface water in St. Margarets Bay during the mid-Holocene interval, with a lower influx of freshwater and, possibly, less mixing with inner shelf water. This may be due to a reduction in the cross sectional area of the entrance to the bay (Fig. 7) at a time when sea level was probably some 15 m lower; this is discussed under relative sea level changes.

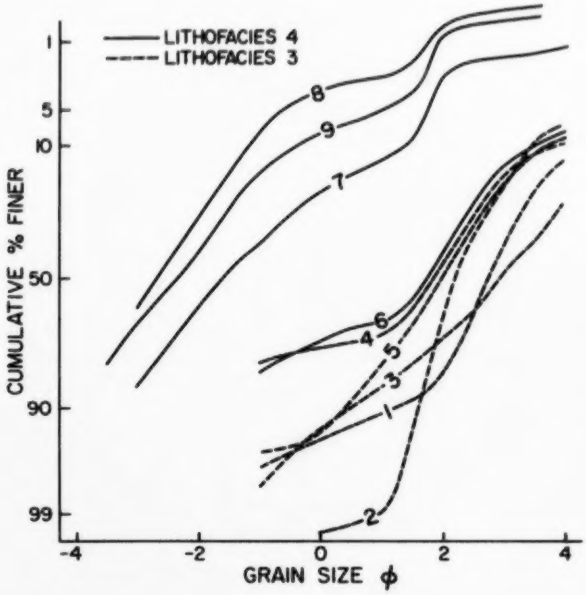


Figure 37. Grain size analyses from sediment facies 3 and 4 (sands and gravels), in core 78-112.

Core 77-12

This core (Fig. 40) is from a water depth of 51 m at the northern edge of the central basin of St. Margaret's Bay, where acoustic unit c may be exposed. The top 11 cm (possibly foreshortened by coring disturbance) is an olive-grey organic-rich mud (facies 1a), similar to that found over much of central St. Margaret's Bay. The unit contains abundant diatoms (ca. 50% planktonic *Melosira* species, 50% diverse benthic pennate taxa) and large numbers of dinocysts (Fig. 41) which correspond to the *Peridinium conicoides – Operculodinium centrocarpum* assemblage in core 74-1. The pollen assemblages (Fig. 41) indicate a mid-Holocene age (zone C1/2).

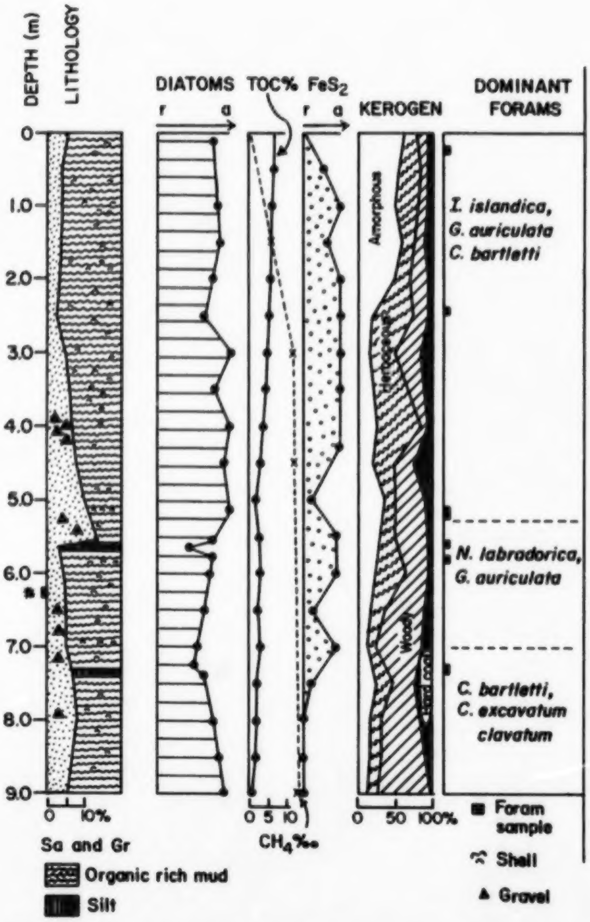


Figure 38. Lithostratigraphy, percentage sand and gravel, diatoms (rare to abundant), total organic carbon (TOC%) and methane (%), pyrite (rare to abundant), kerogen (%) and foraminiferan assemblages in core 74-1. Asterisk indicates a ^{14}C date of 3970 ± 260 BP (Piper and Keen, 1976).

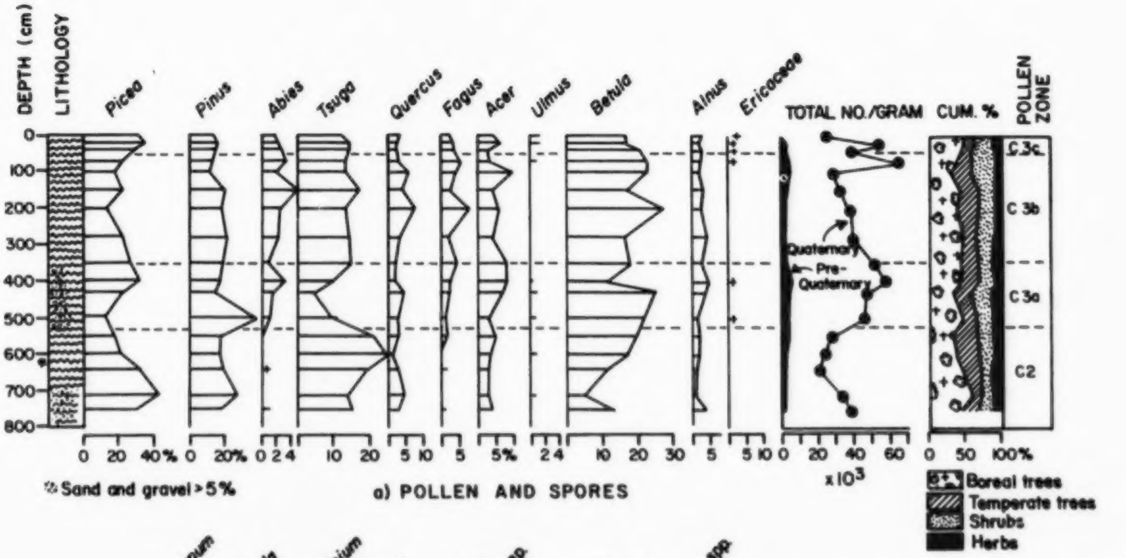
This organic-rich sediment is underlain by a grey silty clay (facies 1b, 11-28 cm) with far fewer diatoms and very low pollen concentrations but moderate numbers of dinocysts. The pollen assemblage indicates the presence of subarctic vegetation and it resembles that found in Silver Lake (Halifax Co.) and Canoran Lake (Lunenburg Co.) with an age of about 10 000 to 11 000 years (Livingstone, 1968; Railton, 1973). The dinocyst species composition is similar to that of the *Operculodinium centrocarpum – Spiniferites* spp. assemblage at the base of core 74-1 and indicates the presence of plankton-productive warm surface water, at least in summer. Foraminifera in this unit have not been sampled.

Table 3. Relative abundance of dinoflagellate cysts and acritarchs in core samples

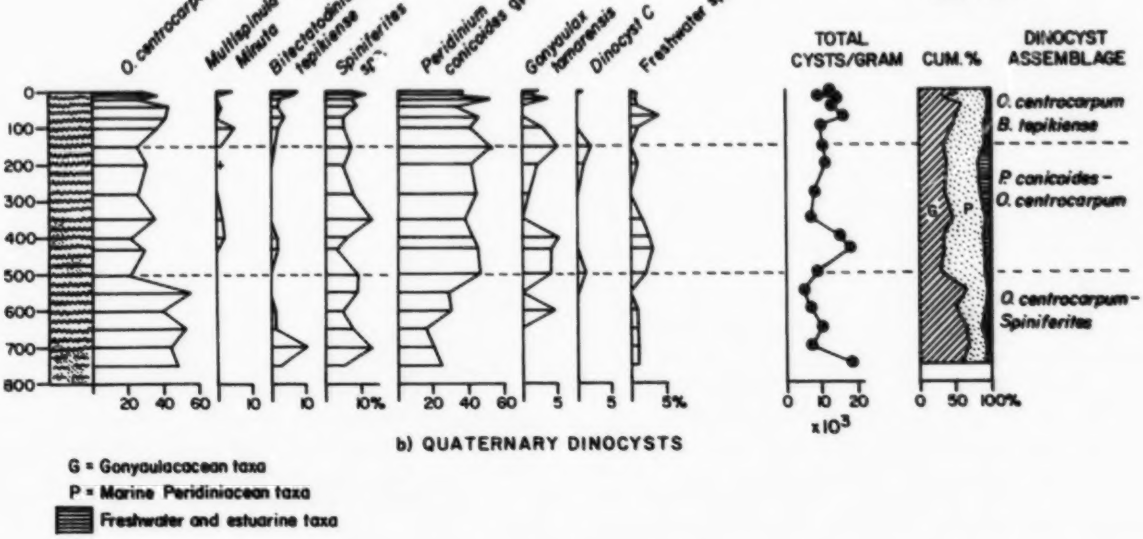
Core No. &	76-04-2	77-002-14			78-05-100				78-05-112				77-002-15	
Sample Depth (cm)	120 cm	65 cm	475 cm	500 cm	60 cm	95 cm	100 cm	125 cm	25 cm	85 cm	101 cm	140 cm	475 cm	500 cm
Species														
Bitectatodinium tepikiense					12	11			5	3		4		6
Dinocyst species C			4			5			2	1	9	1		
Dubridinium cavatum	4	4												
Gonyaulax tamarensis	3	14												
Hemicystodinium zoharyi	3		1	6	16	+		2			1			
Leptodinium patulum	2													
Multispinula quanta		1								3		1		
M. minuta	1				6				24	25	48	27	30	52
Nematosphaeropsis balcombiana					4									
Operculodinium centrocarpum	25	39	31	53	14	31			17	17	3	27		
Peridinium avellana						5			5	5		1		
P. conicoides	23	8	12	6	6	42			43	26	36	24		
P. cinctum		6	1			5								
P. faeroense	3		3							1				
P. wisconsinense												1		
Peridinium – group			18	2	33	11			2	2				
Planinosphaeridium choanum														
Spiniferites bentori			1	1									3	2
S. bulloideus		1		1						1		1		
S. elongatus	7	4	21	21						2			16	22
S. membranaceus										1				
S. mirabilis												2		
S. ramosus	18	1	4	2	19					4		7	3	3
Tectatodinium pellitum	2		3	4										
Leiosphaera species A												2		
Micrhystridium species F		1												
Micrhystridium species S	3	1	3		10									
Total counted	94	77	76	100	66	30	2		62	111			50	50
Number per gram	645	541	2320	1618	2220	811	75		3522	8671			5650	16,800

+ present in slide, but <0.5%.

Facies 2a (28-168 cm) is 140 cm thick and consists of brown clay with dark silty laminae. There are a few shell fragments and pebbles. Pollen concentrations in five samples from this interval are low and mostly indicate an arctic or subarctic environment of late glacial age (Zone G, age >13 000 BP) or early post-glacial age (Zone L, 11 000-13 000 BP). However, the relatively high concentrations of *Pinus banksiana* pollen at a core depth of 130 cm may indicate a warmer climatic interval during which scrubby pine forests were present in areas of well-drained soil along the coast (see discussion of Core 77-15 for more detail). Numbers of pre-Quaternary palynomorphs are relatively high in all samples from this unit and they are dominated by Paleozoic spores which are common in the red till of the Halifax-eastern Lunenburg County area (Mudie, 1980) and in Windsor Group rocks of eastern Nova Scotia (Utting, 1980). However, there are also significant numbers of Cretaceous and Tertiary taxa, the latter indicating that the sources of reworked sediment probably include eroded Scotian Shelf sediments.



a) POLLEN AND SPORES



b) QUATERNARY DINOCYSTS

Figure 39. Lithostratigraphy and palynomorph abundance in core 74-1. Percentage abundances are based on (a) total Quaternary pollen and spores and (b) total Quaternary dinocysts. Asterisk indicates a ^{14}C date of 3970 ± 260 BP (Piper and Keen, 1976).

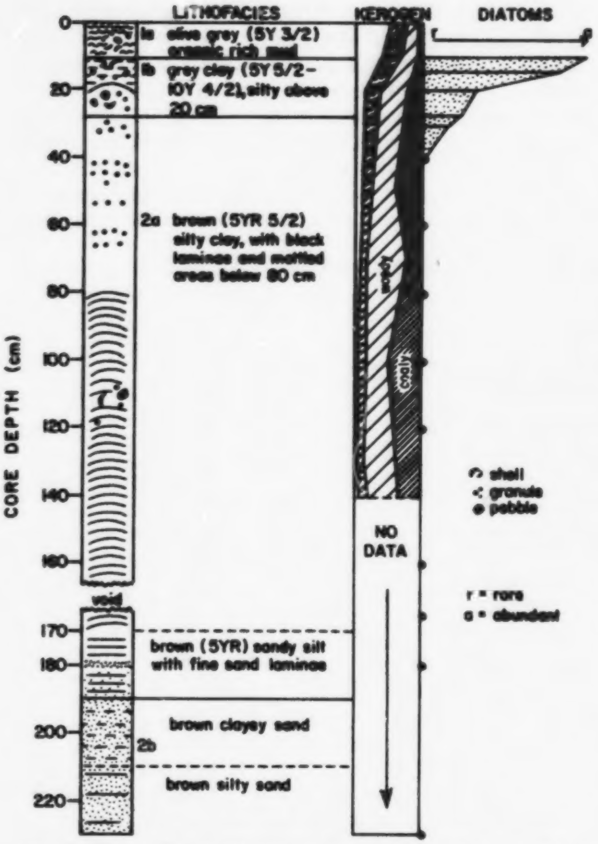

LITHOFACIES
KEROGEN
DIATOMS
CORE DEPTH (cm)
0
20
40
60
80
100
120
140
160
170
180
200
220
1a olive grey (5Y 3/2) organic rich mud
1b grey clay (5Y 5/2-10Y 4/2), silty above 20 cm
2a brown (5YR 5/2) silty clay, with black laminae and mottled areas below 80 cm
void
brown (5YR) sandy silt with fine sand laminae
brown clayey sand
2b
brown silty sand
coaly
NO DATA
r
a
shell
granule
pebble
r = rare
a = abundant

Figure 40. Lithostratigraphy, percentage of types of kerogen, and diatom abundance in core 77-12. Symbols for kerogen types as in Figure 38.

In facies 2a of core 77-12, diatoms are present only in sediment at the top of the section and in very low numbers. A sample of foraminifera from 64 cm core depth contains moderate numbers of benthic species dominated by *Cribrononion excavatum f. clavatum* (=*Elphidium excavatum* f. *clavata*). Dinocyst numbers in the sample from 50 cm core depth are low but the dominance of *O. centrocarpum* suggests subarctic surface water and a salinity of greater than 32‰ (Mudie and Short, 1983). Dinocysts in samples at 65 100, and 130 cm, however, indicate a strong freshwater influence and, probably, subarctic surface water temperatures. The cyst assemblage from 145 cm core-depth contains very low numbers of the ice-margin indicator, *Leiosphaera* species A (?Dinocyst sp. R of Mudie, 1980), in addition to freshwater cyst taxa and the arctic water indicator *Multispinula minuta* (see Mudie and Short, 1983).

Facies 2b (penetrated for 35 cm) in core 77-12 consists of brown sandy mud and has a gradational contact with facies 2a. No palynological samples were taken but a sample of foraminifera from 210 cm contains extremely low numbers of benthic specimens dominated by *C. excavatum clavatum*. Diatoms appear to be absent both in this unit and at the base of facies 2a.

Core 76-2

This core collected in 33 m water depth in the Southern Basin of Mahone Bay was described briefly by Barnes and Piper (1978). The core was collected at the basin margin, where MS26-B echosounder profiles show that surface sediment of acoustic unit d pinches out over the stratified acoustic unit c. Facies 1 (0-70 cm) corresponds to acoustic unit d and consists of olive-grey organic-rich silty mud (Fig. 26). Facies 1a (0-50 cm) has an open-bay foraminiferal assemblage (using terminology of Bartlett, 1964). The lower 20 cm (facies 1b) has a high diatom content and it contains foraminifera species assemblages which closely resemble those found in modern sediment of sheltered basins in northeastern Mahone Bay.

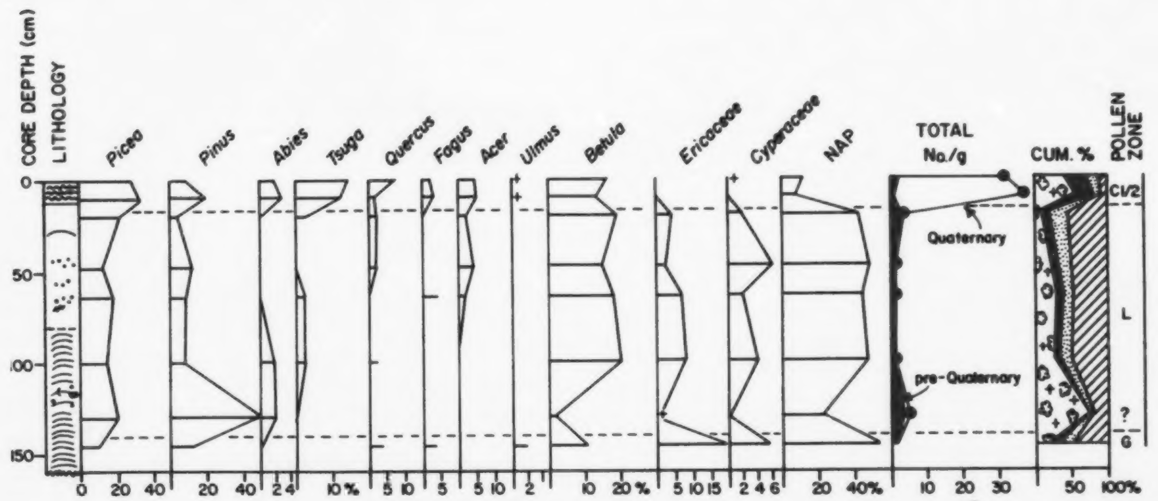
Facies 2 (70-130 cm) in core 76-2 consists of 60 cm of alternating silt and clay laminae, with clay being most abundant in the upper part of the unit. Both silt and clay beds are well sorted and are undisturbed by bioturbation. Foraminifera numbers are low and the assemblages do not show much variation between silt and clay laminae when sampled at close intervals. The species of foraminifera (mainly *Eggerella advena* and/or *C. excavatum*), and the relatively common copepods and ostracodes suggest a brackish or freshwater environment with an occasional oceanic influence. A palynological sample from 120 cm core depth contains low concentrations of Quaternary pollen, spores and dinocysts and a relatively high percentage frequency (45%) of reworked Paleozoic and Tertiary palynomorphs. The presence of several deciduous tree pollen species (Table 2) suggests that the sample is of an early Holocene age (zone A/B); hence, the high percentage of herb taxa (NAP) may reflect the local presence of marsh vegetation. However, the low pollen concentrations and the paucity of freshwater dinocysts could indicate that the sample represents a marine sediment of late glacial age (L-zone). The dinocyst species (Table 3) indicate a relatively warm, nearshore marine environment.

Facies 2 in core 76-2 is underlain by gravel which was not penetrated by the 600 kg corer at this or the adjacent core sites 76-4 and 76-7. Foraminiferan assemblages in samples from just above the bases of these cores contain moderate to very low numbers of nearshore marine or brackish lagoon species, including *E. advena*, *C. excavatum*, *Protelphidium orbiculare* and *Saccamina atlantica*.

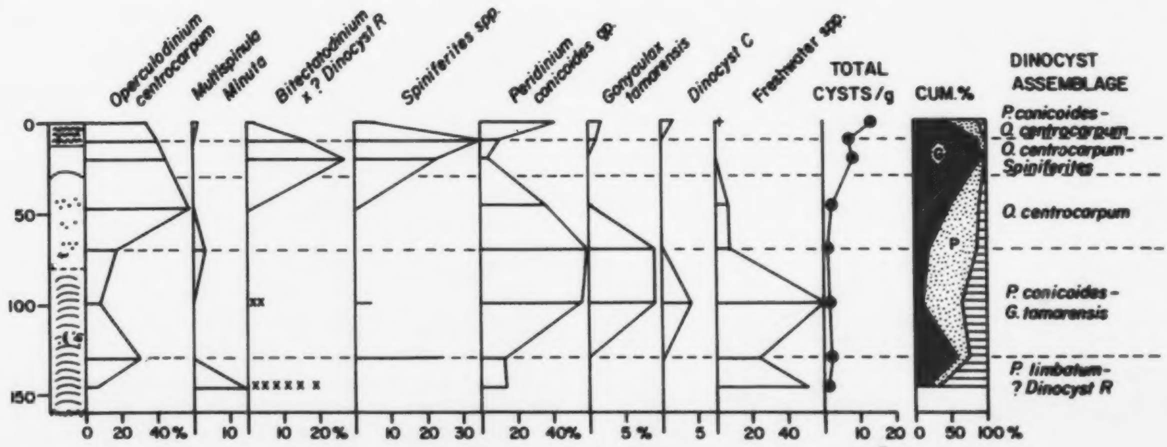
Core 77-16

This core is also from the southern basin of Mahone Bay, but is much closer to the sill, and was collected in 37 m of water. The core-catcher recovered grey silty clay similar to facies 2 in core 76-2, but the core proper consists of about 4 m of olive-grey silty mud and muddy sand correlatable with facies 1 in core 74-1 (Fig. 26). The top 55 cm consists of very fine sand, passing down into 250 cm of silty mud. This overlies 50 cm of sand with scattered shells and pebbles; a sample from 343 cm contains an open bay foraminiferal assemblage, with numerous nearshore species, dominated by *Eggerella advena*. This sand rests on 10 cm of gravelly sandy mud. Shells collected from the entire basal sand unit give a ^{14}C date of 4140 ± 185 BP (GX-5736), suggesting that the basal gravelly sandy mud has a radiocarbon age of 4000-4500 years. This is interpreted as the date of final breaching of the barrier beach at the entrance to Mahone Bay during the Holocene transgression (Barnes and Piper, 1978). The upward fining sequence into silty mud represents a gradual increase of sea level, whereas the sand at the top of the core may result from the submergence of the protective shoal at Middle Ledge (Fig. 3).

Palynomorph assemblages were studied in 10 samples from core 77-16 (Mudie, 1980). Pollen and spore concentrations are low (2 000 – 11 000/g dry sediment) in the sandy or silty mud for such an outer bay site but they largely comprise Quaternary taxa, the composition of which is consistent with a younger Holocene date for the base of facies 1 in this core. The pollen and spores in the grey silty clay from the core catcher indicate a mid-Holocene (zone C2) age. The dinocysts throughout facies 1 in core 77-16 are characterized by relatively low cyst concentrations which are dominated by *Operculodinium centrocarpum*, *Peridinium conicoides* and a diversity of *Spiniferites* species. A similar dinocyst assemblage is found in a tidal channel of Halifax Harbour and at the seaward end of LaHave estuary (Mudie, 1980); this assemblage appears to characterize open outer bay environments overlain by warm turbulent water. The dinocyst assemblage from the base of core 77-16, however, contains a relatively high percentage of freshwater taxa, suggesting a stronger fluvial influence and more estuarine type of environment.



a) POLLEN AND SPORES



b) QUATERNARY DINOCYSTS

Figure 41. Lithostratigraphy and palynomorph abundances in core 77-12. Percentage abundances are based on (a) total Quaternary pollen and spores, and (b) total Quaternary dinocysts. Symbols for cumulative per cent are as used in Figure 39.

Core 78-100

Several coring attempts were made in 20-30 m water depth at the entrance to Lunenburg Bay east of the Ovens (Fig. 21). Core 78-100 in 25 m water depth (Fig. 42) and three other cores (Scott and Medioli, personal communication, 1979) penetrated a surface sand in this area which overlies an olive-grey mud. The foraminiferal assemblages were studied in detail in core 78-100 by Scott and Medioli (1982). Palynomorph assemblages were sampled at four intervals in this core.

The top 64 cm of core 78-100 is a shelly sand, locally gravelly and commonly in small graded beds. Foraminifera in this interval are abundant and indicate a nearshore environment in which a high diversity of foraminiferan species are present, dominated by *Cibicides lobatulus*. The pollen and spores in the palynological sample from 60 cm core depth (Table 2) indicate a mid-Holocene age (zone C2), whereas the dinocyst species composition (Table 3) is characteristic of a nearshore marine environment overlain by warm surface water.

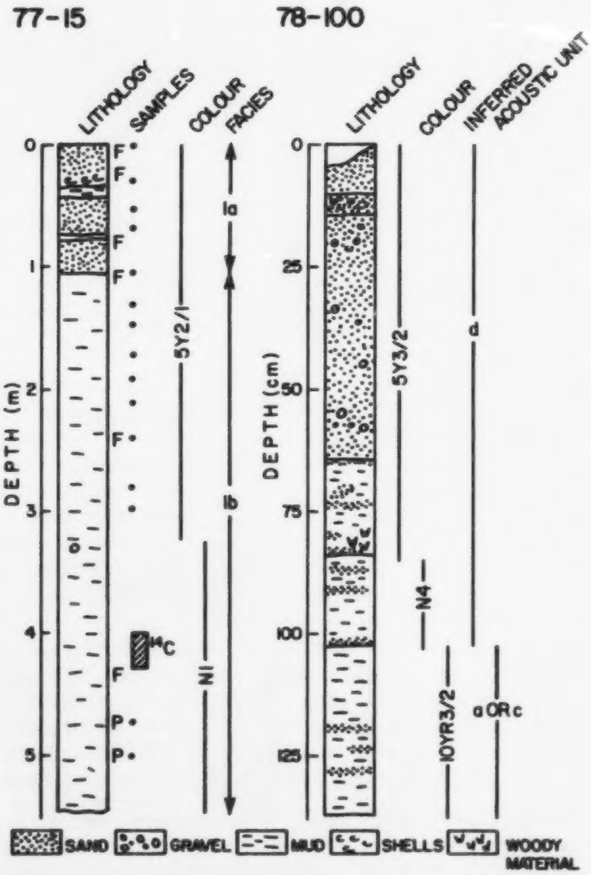


Figure 42. Lithostratigraphy in cores 77-15 and 78-100.

In core 78-100, this nearshore facies overlies about 20 cm of bioturbated olive-grey mud which contains medium and coarse sand, rare wood and shell fragments from 64-85 cm in the core (Fig. 42). A sample of wood fragments from the 80-84 cm interval has a ^{14}C age of 7070 ± 300 BP (Scott and Medioli, 1982). This mud contains relatively low numbers of foraminifera, the species of which decrease in diversity towards the base of the interval and indicate a littoral environment. Scott and Medioli (1982) found that the foraminifera between 70 and 85 cm core depth are dominated by *Trochammina inflata* and *T. macrescens* which indicate a salt marsh environment deposited within a 30 cm range of MHHW (Scott and Medioli, 1978).

The sandy mud with wood and shells is underlain by about 20 cm of laminated grey clay, with rare sandy laminae and granules, from 85-103 cm in the core. Scott and Medioli (1982) found this clay contains abundant foraminifera similar to those in the upper part of the core, and pollen and spores in a sample of grey clay from 95 cm core depth are dominated by *Picea* and *Tsuga* pollen, suggesting an age of around 7500 years. The dinocyst assemblage in this sample is similar to that found in modern subtidal channels of Chezzetcook Inlet (Mudie, 1980).

Below 103 cm in core 78-100 is a yellowish brown laminated clay with thin bands of grey sand or clay. This clay facies is lithologically similar to facies 2a from core 77-12 in St. Margaret's Bay. However, it contains few palynomorphs and only very low numbers of nearshore foraminiferan species (Scott and Medioli, 1982). Samples from 100 and 125 cm contain Paleozoic spores and fragments of highly altered wood and hard coal but Holocene palynomorphs are very rare or absent (Table 2). Seismic reflection profiles suggest this facies is part of acoustic unit b or c.

Scott and Medioli (1982) suggested that since the marsh sequence around 80 cm core depth is both overlain and underlain by fully marine sediments, it must represent a point of transition from coastal emergence to coastal submergence. They argued that the unconsolidated nature of the core sediments suggest no unconformities are present in core 78-100. However, the abrupt change in both sediment type and microfossils at 103 cm may indicate a major disconformity between late-glacial and mid-Holocene sediments. Furthermore, the sequence from 103 cm to 85 cm could equally well represent sediment progradation as a fall in sea level, although Scott and Medioli (1982) argued that the observed foraminiferal succession would require at least 5 m of aggradation. Thus, although this core establishes a relative sea level of about −25 m at 7000 BP, the evidence for an inflection point in sea level history is equivocal. The inflection point may be much older, thus producing a major disconformity. If so, the core may indicate a relatively high stand of sea level in late glacial times, which permitted accumulation of the basal 33 cm of mud containing reworked palynomorphs and rare marine foraminifera, followed by an erosional interval during the sea level minimum, and renewed accumulation during the late Holocene rise in sea level.

Core 77-14

This core site is located in 35 m of water at the edge of a sand basin between LaHave Island and West Ironbound Island, where seismic reflection profiles show that acoustic unit c (possibly unit b) occurs close to or at the seafloor (Fig. 17). The top 35 cm consists of alternating gravelly sandy mud and mud. Beneath this is 40 cm of mud with rare layers of woody fragments, which yielded a radiocarbon date of 10 985 ± 280 BP (GX-7633) at 50 cm. Foraminifera are absent in the sandy sediment from a sample at 34 cm depth in the core but a sample of the mud at 46 cm contains three foraminifers, including two specimens of *Trochammina inflata* which suggest an intertidal marsh environment.

A palynological sample from near the base of the mud, at 65 cm core depth, contains low numbers of pollen and spores. This assemblage is dominated by *Picea* and *Betula* (including a high percentage of tundra shrub *Betula minor*–type pollen) and by a high frequency of herb vegetation indicators. These Quaternary pollen and spores suggest a late glacial age (L zone: 11 000-12 000 BP) for the base of the mud unit. The presence of abundant *Sphagnum* moss leaves in this sample suggests the proximity of a freshwater marsh. The dinocyst assemblage includes a mixture of marine and estuarine or freshwater taxa; this assemblage most closely resembles that of an intertidal mudflat or a subtidal salt-marsh channel. A similar palynomorph assemblage is found at the top of a brackish water sediment interval in a core from Bedford Basin that has been dated at 7705 ± 550 BP (Miller et al., 1982).

The basal 260 cm (facies 4) of Core 77-14 is a graded bed of well sorted fine pebbly gravel, passing up into coarse sand. (The top 10 cm appears reworked, with poorly sorted pebbly sand.) No trace of marine organisms has been found. The grading and sorting of the sediment in facies 4 of Core 77-14 suggest a fluvial or fluvioglacial sediment. Similar thick graded beds are found in nearby Core 77-13.

Core 77-15

This core was collected from an inner shelf basin, 5 km southeast of Cross Island, in 66 m of water (Fig. 20, 43). The top 100 cm (facies 1a) consists of grey fine and medium sand, with occasional silty or clayey laminae containing shell fragments (Fig. 42). Foraminifera in two samples from the upper part of facies 1a comprise an inner shelf assemblage of diverse species, predominately *Cribrononion excavatum clavatum, Islandiella islandica, Buccella frigida* and *Eggerella advena*. Large numbers of foraminifera are also present in the sample from 84 cm core depth but this assemblage is lower in species diversity.

Facies la in core 77-15 is underlain by olive-grey silt (facies 1b) which becomes finer downwards and at 320 cm grades to a silty olive-grey mud with gas expansion cracks. The sand content is approximately 10% in the silt and less than 3% in the mud. Foraminiferal numbers in samples from this unit are low and cannot be interpreted with certainty. The foraminiferan assemblages in the gassy mud samples suggest a bay environment, with the presence of *Cibicides lobatulus, Cassidulina crassa* and *Bucella frigida* possibly indicating a strong exchange of water with the open shelf. *Cribrononion excavatum clavatum* is well represented in both samples from facies 1b which suggests that the low foraminiferal number reflects a high sedimentation rate rather than diagenetic alteration (see Schnitker et al., 1980).

Total organic carbon in the mud from the base of the core (400-425 cm) gave a radiocarbon date of 14 000 ± 200 BP(I-10467). Palynological samples from depths of 475 and 500 cm contain low numbers of pre-Quaternary palynomorphs and very little reworked thermally altered kerogen, thus supporting the probable accuracy of this radiocarbon age. However, the concentrations of Quaternary pollen and spores (Table 2) are relatively high compared to the late glacial pollen assemblages in most Nova Scotian lakes, although a similar pollen assemblage was found at the base of a core from Leek Lake which has an age of older than 12 900 years (Wightman, 1980). These apparent anomalies are most simply explained by assuming the presence of tundra-woodland vegetation in coastal plain and mountain-top refugia during the last glacial stage. Core 77-15 lies south of the late-till margin (acoustic units b and c). Palynological data from Emerald Basin, located about 50 km southeast of Cross Island, also suggest the presence of a coastal refugium older than 12 100 years (Mudie, 1980).

Relatively high concentrations of Quaternary dinocysts in the samples from the base of core 77-15 (Table 3) suggest the presence of nutrient-rich water which was ice-free at least during summer. The dinocyst assemblage, which is dominated by *Operculodinium centrocarpum* and *Spiniferites elongatus*, suggests an environment with warm surface water in summer and a relatively low influx of fresh water. Similar

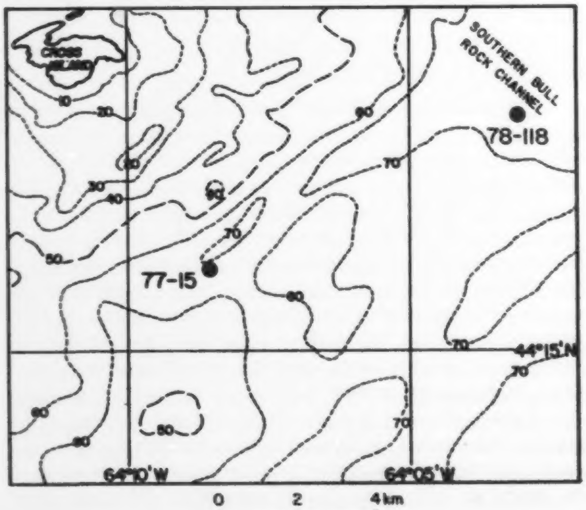


Figure 43. Bathymetry of area southeast of Cross Island showing location of cores 77-15 and 78-118. Contours in metres.

dinocyst assemblages are found in the pre-Holocene Emerald Silt in core 80-004-34 from Canso Basin south of Cape Breton Island (Scott et al., 1982).

If the fine sediment at the base of core 77-15 was to accumulate under present wave and current conditions, a sea level lowering of at least 60 m would be necessary so that the site would have been protected from the open sea by the shallow shoal to the south (Fig. 43). However, D.B. Scott (personal communication, 1981) believed the presence of *Cibrostomoides crassimargo* and *Saccammina atlantica* indicates water depths of at least 20 m. If this is the case, ice damping of waves may have permitted the accumulation of fine sediment.

Core 78-118

This core was obtained from a water depth of 80 m in southern Bull Rock channel east of Cross Island. The channel appears to form a deeper, eastward continuation of the basin from which core 77-15 was recovered (Fig. 43). There was probably a thin surface sand layer washed out at the top of this core because two other attempted gravity cores washed out. The top 80 cm of core 78-118 (Fig. 26) consists of grey shelly silty mud (facies 1b). A sample of foraminifera from 45 cm core depth contains an open shelf fauna while a sample from near the base (75 cm) contains a foraminiferal assemblage characteristic of the modern turbulent nearshore zone, again suggesting that sea level was substantially lower when these sediments accumulated. This silty mud facies in core 78-118 probably correlates with facies 1b of core 77-15.

In core 78-118, facies 1b is underlain by 30 cm of sediment which is transitional between the grey shelly mud and the compact brown laminated mud found below a core depth of 110 cm. This transitional sediment (facies1c) contains a foraminiferal assemblage similar to that which occurs at the base of facies 1b but it has a much lower foraminiferal number and a less diverse fauna.

Facies 2 in core 78-118 (110-290 cm) correlates with acoustic unit c and contains a foraminiferal fauna dominated by *Cribrononion excavatum clavatum*, with relatively high foraminiferal numbers and species diversity in the samples between 110 and 230 cm but much lower numbers and diversity in the samples from the lower section of this unit. The foraminiferal assemblage from 133 cm and lower levels in Core 78-118 corresponds to the "warm" ice margin fauna of Scott and Medioli (1980a,b). It also closely resembles the *Elphidium clavatum* assemblage found by Vilks and Rashid (1976) in sediment from Emerald Basin which has a radiocarbon age of about 15 000 BP. This "warm" ice margin fauna is characterized by strong dominance of *C. excavatum* f. *clavatum* (40-80% of the fauna) and is believed to indicate an ice margin that is at the melting point in summer. The lower foraminiferal number in core 78-118 suggests a more rapid sedimentation rate at this site than in Emerald Basin. The base of core 78-118 consists of about 30 cm of poorly sorted gravelly mud and probably has a similar origin to facies 3 of core 78-112 which is described below.

Core 78-112

This is one of four cores collected 25 km offshore from Cape LaHave in 120 m water depth, in a sediment-filled valley near the southwest corner of the detailed survey area south of Cross Island (Fig. 21). There is a surface veneer of muddy sand (facies 1a, Fig. 35) with low numbers of open shelf foraminifera. This muddy sand overlies 100 cm of olive-grey mud (facies 1b) with rare shell fragments. Samples of foraminifera from facies 1b (at 23 and 83 cm) contain large numbers of species which are similar to those presently found in the surface sediment of Emerald Basin.

Pollen and spores from samples at 25 and 85 cm in core 78-112 contain large numbers of tree pollen species which are dominated by *Picea*, *Pinus* and *Tsuga*, and low numbers of deciduous tree pollen species (Table 2). These pollen assemblages may indicate the age of the sediment to be about 5000-7000 years (zone C2). However, the relatively high percentage frequencies (21-24%) of pre-Quaternary palynomorphs suggest that much of the Quaternary pollen is reworked, indicating that the sediment could be pre-Holocene in age. Abundant dinoflagellate cysts in these samples are dominated by *Peridinium* conicoides, Operculodinium centrocarpum and *M. minuta* (Table 3). These assemblages most closely resemble those presently found off southeastern Labrador and they suggest an open shelf environment overlain by rather cold, low salinity surface water.

Facies 1 in core 78-112 overlies about 250 cm of brown clayey mud (facies 2) with abundant dark (pyritic) silty laminae corresponding to the upper part of acoustic unit a. The basal 40 cm has thin beds of very fine-to medium-grained sand. A sample from the top of facies 2 (112 cm) contains abundant foraminifera which are dominated by *Cribrononion excavatum clavatum* and *Cassidulina crassa*, forming an assemblage similar to that found at the top of facies 2 in core 78-118 and suggesting a "warm" ice-margin environment (Scott and Medioli, 1980b). The sample from 135 cm has a much lower foraminiferal number and species diversity which probably indicates a higher sedimentation rate for this interval. Samples from 175, 234 and 285 cm are barren.

Palynological samples from 101 and 140 cm core depths in facies 2 of core 78-112 contain low concentrations of Quaternary pollen and spores which indicate a sparsely vegetated (periglacial?) landscape. A high percentage frequency of Paleozoic spores in the sample from 101 cm suggests the influx of significant amounts of glacially-eroded sediment, and both samples have pollen assemblages that would suggest early post-glacial (zone L) or late-glacial (zone G) age. Moderately high concentrations of dinocysts are present in both samples from facies 2. The dinocyst assemblages are dominated by the arctic water indicator *Multispinula minuta*. The presence of *Leiosphaera* species A in the sample from 140 cm suggests the proximity of an ice margin.

Facies 2 in core 78-112 is underlain by about 80 cm of poorly sorted fine- to medium-grained sand with a muddy matrix in the upper part and scattered pebbles throughout (facies 3). This sediment was sampled for foraminifera near the base, at 430 cm core depth. The sample contained relatively low numbers of foraminifera, dominated by *Cribrononion excavatum incertum*, *Cibicides lobatulus* and *Islandiella isandica*, which may indicate a nearshore environment. Below facies 3, 100 cm of gravelly sand (facies 4) occurs which forms a well sorted bed with 2 cm of gravel at the base and well developed grading to coarse sand at the top. Foraminifera were not found in samples from facies 4 in core 78-112, which is similar to the graded gravels and coarse sand in cores 77-13 and 77-14 from the outer LaHave estuary.

Stratigraphic summary

Acoustic unit d corresponds to the LaHave Clay (d1) and Sable Island Sand and Gravel (d2) of King (1970). Lithologically it consists of facies 1, ranging from muds through muddy sands to sands. Foraminiferal assemblages in the cores indicate conditions either similar to or shallower than those at the present core surface. The base of the unit is diachronous, with approximate dates ranging from 4500-5000 BP in Mahone Bay, 8000 BP in St. Margaret's Bay, 7070 BP in Lunenburg Bay, 11 000 BP in the LaHave estuary to more than 14 000 BP in the basin south of Cross Island. The older parts of this unit may therefore be equivalent to the uppermost part of the Emerald Silt of King (1970).

Acoustic unit c appears similar to parts of the Emerald Silt of King (1970). Lithologically, it consists of facies 2 and 3 — laminated muds passing down into sands. It underlies acoustic unit d, commonly disconformably, and thins southwards. In nearshore areas the microfossils in facies 2 indicate accumulation in fluvially influenced estuarine environments and palynological samples imply a late glacial (13 000 years) to early postglacial (10 000-12 000 years) age. In offshore areas, the inferred age is older than 14 000 years, and microfossils suggest a "warm" ice margin marine environment. The lower parts of facies 2 indicate a high rate of sediment deposition and rather low organic productivity. The passage to facies 3 is gradational. Facies 3 is a marine deposit, probably from an ice-margin environment.

Acoustic unit b corresponds, where cored, to facies 4: sands and gravels apparently lacking marine fossils. It underlies acoustic unit c, passes laterally into till and thins rapidly southwards. Whether it is a marine or terrestrial deposit, or both, is uncertain. Except that it is more than 14 000 years old, its age is unknown.

Late till extends only a short distance south of the present shoreline, between Cape LaHave and Pearl Island, and interfingers with acoustic units b and c. It has not been recognized elsewhere. At its seaward limit, it is older than 14 000 years and is thus tentatively correlated with the classical late Wisconsinan ice advance.

Acoustic unit a forms a widespread drape over bedrock, till, and locally, stratified sediments. It is lithologically similar to acoustic units b and c, with facies 2 passing down into 3 and 4. Microfossils at the top of facies 2 suggest a "warm" ice-margin environment. There is no direct evidence of the age of this unit, but it overlies the early till.

Early till extends seawards to the Pennant Point moraine as a discontinuous sheet, and it thus appears to be at least 26 000 years old (L.H. King and G.B. Fader, personal communication, 1983).

Relative sea level changes

Introduction

The Atlantic coast of Nova Scotia has experienced a variable rate of relative sea level rise of 1.5-7 mm/a over the last 7000 years (Grant, 1970; Scott, 1977; Scott and Medioli, 1978, 1982). The earlier history of relative sea level is uncertain. Quinlan and Beaumont (1981) have modelled sea level changes due to glacial ice loading, and predicted the migration of a marginal bulge following ice retreat. They suggested that late Wisconsinan ice limits slightly seaward of Grant's (1977) 'minimum model' most closely fit geological data on Holocene relative sea level change throughout Atlantic Canada. They predicted that relative sea level has risen continuously on the outer shelf since a late Wisconsinan minimum, but that along the Atlantic coast of Nova Scotia there was a short period of falling relative sea level following deglaciation, succeeded by a continuous rise.

The maximum Wisconsinan sea level lowering on the Scotian Shelf is not known with certainty. King (1967) recognized a widespread terrace at –115 m on the Scotian Shelf, across which there are pronounced changes in sediment characteristics. Quinlan and Beaumont's (1981) model indicated that a lowering of more than 70 m was improbable, and Scott and Medioli (1982) suggested an early Holocene maximum lowering of only 27 m near Lunenburg, preceded by a high sea level stand.

New data

New data on sea level change (Fig. 44) are summarized below. Most of the data sources have been discussed in more detail in the previous section "Piston core biostratigraphy".

(i) Data points from peaty muds or wood suggest sea level has gradually risen by about 35 m during the past 11 000 years, as suggested by previous authors (Grant, 1970; Quinlan and Beaumont, 1981).

(ii) The widespread planar unconformity at the base of acoustic unit c is evidence of a lowered stand of sea level which appears analogous to King's (1967) –115 m lowering. This regular planar pattern of erosion that truncates the top of acoustic units a and b is most easily accounted for by marine planation at a coastline. In an area of such irregular bathymetry, this truncation surface is difficult to explain by any other marine erosion process. The unconformity appears approximately synchronous with the late till (Fig. 18), to which an assumed age of 18 000 years has been assigned (Fig. 44). This sea level lowering presumably corresponds to the New Guinea sea level minimum around –120 m at about 20 000 BP (Bloom et al., 1974). The unconformity has a maximum depth of 120 m below present sea level, which decreases landwards to –60 m (Fig. 25), presumably as a result of marine transgression.

(iii) Prior to this lowered stand, sea level must have been much higher, since acoustic unit a which underlies the late till is found in water depths as shallow as –58 m. The age of acoustic unit a is uncertain, but is assumed to be about 23 000 years (Fig. 44), based on correlation with the youngest pre-late Wisconsinan interstadial in offshore cores (Hill, 1981; Alam, 1979).

(iv) The history of sea level changes from the time of the major lowering synchronous with the late till up to the –35 m level at 11 000 BP is poorly constrained. Several hypotheses are tenable with the limited data available. There may have been a simple transgression (A in Fig. 45), or there may have been a rapid sea level rise to

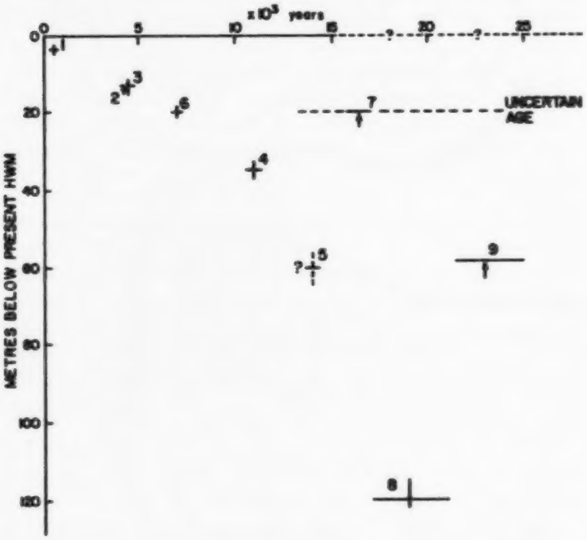
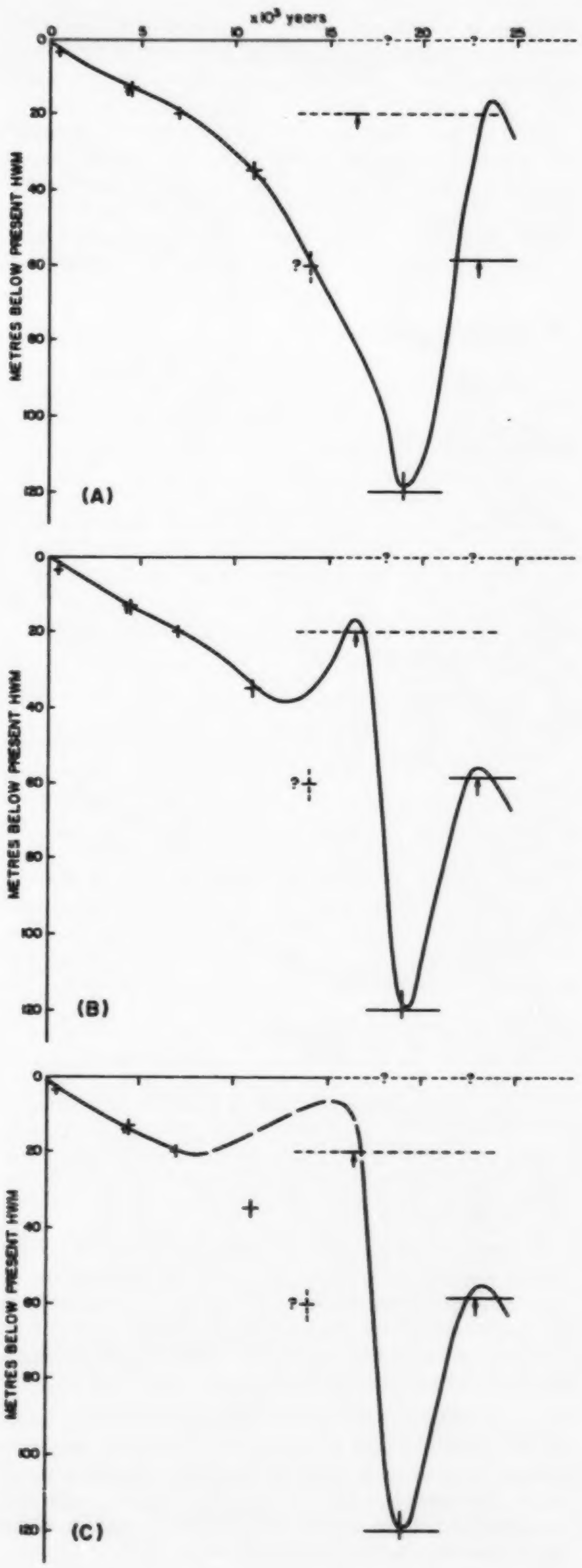


Figure 44. New data on sea level change. For further discussion see text. Details of ¹⁴C dates given in Table 1. Note that time scale before 15 000 years is speculative.

1. Saltmarsh peat from 3.1 m below HWM on the foreshore of Hirtles Beach (Hartling Bay); 785 ± 80 BP (I-9930, Urquhart, 1976).
2. Peat (possibly allochthonous) from –14 m at the south end of Green Bay; 4170 ± 80 BP (GSC-2128).
3. Core 77-16 suggests sea level at around –14 m about 4000 to 4500 years (Barnes and Piper, 1978).
4. Core 77-14: –35 m at 10 985 ± 280 BP (GX-7633).
5. Mud in core 77-15 may suggest sea level at about –60 m about 14 000 BP (I-10 407) or ice-damping of waves and a higher sea level.
6. Core 78-100: salt marsh peat at –27 m about 7000 years (Scott and Medioli, 1982).
7. Core 78-100: brown clay below 103 cm suggests sea level higher than –27 m during the deposition of either acoustic unit c or a.
8. Erosion surface at –60 to –120 m synchronous with the late till.
9. Deposition of acoustic unit a in water depths of as little as 58 m indicates a relatively high stand of sea level.



high stand while the ice margin was still close to the present coastline (B or C in Fig. 45). The choice between the first hypothesis and B or C depends on the interpretation of the age of the yellowish brown clay with rare foraminifera below 103 cm in core 78-100. This is evidence of a high stand of sea level of less than –27 m, although it is not clear from seismic profiles whether this clay corresponds to acoustic unit c, above the late till (i.e. B in Fig. 45), or acoustic unit a, below the late till (i.e. A in Fig. 45). Correlation with acoustic unit a is unlikely, however, because the late till ice margin lay some 10 km south of core 78-100 and acoustic unit a would likely have been either substantially compacted or removed by erosion. No trace of acoustic unit a is seen on a seismic profile across core site 78-100, nor elsewhere in Lunenburg Bay, whereasacoustic units b or c are widespread. The rapid postglacial sea level rise is supported by evidence in the Gulf of Maine for a high stand of relative sea level at 16 000 years or earlier (Scott and Medioli, 1980b). This sea level rise was followed by a lowering (as predicted by Quinlan and Beaumont, 1981) to deeper than –35 m sometime between 15 000 and 11 000 B.P., and a gradual transgression since that time (B in Fig. 45). The hypothesis of an early postglacial high stand of the sea was also proposed by Scott and Medioli (1982) from core 78-100, although their low-stand inflection point at 7000 years (C in Fig. 45) is inconsistent with the 11 000 year date from core 77-14 in La Have estuary. The deposition of mud at 14 000 BP in core 77-15 indicates sheltered conditions which may be due to either a 60 m lowering of sea level or ice-damping of waves at a time when sea level was high. The former explanation is consistent with a gradual rise in sea level, as in hypothesis A (Fig. 45); ice-damping of waves must be invoked if hypothesis B or C is correct.

Late Glacial geological history of the South Shore

The style of glacial features varies from west to east through the South Shore region. Drumlins are much thicker and more widespread in the east, even if a belt of drumlins were to formerly have extended offshore in the western area (Fig. 31). Rinnentaler are much commoner and deeper in the east; hence, the absence of early Holocene sediments in the west may be related to the lack of channels in which they could be preserved during rising sea level. Recessional features such as moraines and eskers are absent in the east, but become much more common in southwest Nova Scotia (Grant, 1971).

The lack of recessional moraines and the abundance of rinnentaler suggests that ice in the South Shore region disappeared by a process of stagnation and downwasting (H.B.S. Cooke, personal communication, 1975), with a lack of major readvances. This can be accounted for by marine drawdown towards the Bay of Fundy (Grant, 1970) which isolated the ice mass over South Mountain. This was presumably a feature of many successive glaciations. In the later Wisconsinan, New Brunswick ice appears to have deposited till at Salmon River (Fig. 1) sometime after the 38 000 BP interstadial beds (Nielsen, 1976; Grant, 1976) while marine incursion into the Bay of Fundy took place as early as 16 000 BP (Scott and Medioli, 1980b) and the Bay of Fundy – Minas Basin may have been ice free throughout the late Wisconsinan maximum at around 18 000 BP (Amos, 1978; Grant, 1977). Ice flowing southward from New Brunswick may have been diverted by North Mountain, resulting in flow either westwards down the Bay of Fundy or southwards through the western Minas Basin and Avon Valley, thereby leaving ice in southwestern Nova Scotia close to an equilibrium thickness for an isolated South Mountain centre. Marine incursion into the Bay of Fundy could thus lead to stagnation of ice in the eastern part of the South Shore (south of the Avon Valley) while equilibrium flow persisted in the thinner ice in the west. The recessional features in the west result from this persistence of equilibrium conditions, while in the east the drumlins reflect the initial thick ice conditions and the rinnentaler were produced during stagnation.

Figure 45. (facing) Three possible hypotheses for relative sea level changes, South Shore. The hypotheses are discussed in the text.

The most complete late Wisconsinan record was seen east of Cape LaHave (Fig. 46, 47). At least in water deeper than 50 m, there is an early till sheet, that extends at least 50 km offshore to the Pennant Point moraine and appears to predate the 18 000 year Late Wisconsinan maximum. The extent of this till and its lithological composition inferred from gravel petrology suggest that it forms part of an extensive till sheet that was derived from ice moving from the north across the Cobequid Hills. It thus probably correlates with Stea's (1982) Hants Till in central Nova Scotia, and the red drumlin tills on land on the South Shore. The cutting of major rinnentaler into bedrock is probably a pre-late Wisconsinan phenomenom; the latest phase of flushing of the rinnentaler probably immediately postdates deposition of the early till sheet.

There are two possible models for the origin of the draped acoustically transparent character of acoustic unit a which overlies this early till. It may resemble the 'conformable cover unit' described by Barrie and Piper (1982) from Makkovik Bay (Labrador), which was deposited from surface plume of suspended sediment during rapid ice retreat, without significant wave resuspension. If so, sea level must have been sufficiently low to produce confining valleys which could maintain a freshwater plume. However, the widespread distribution of acoustic unit a (from –58 m off Lunenburg Bay to –130 m 25 km offshore) suggests this interpretation is unsatisfactory. Alternatively, the unit may have been deposited from suspension beneath floating ice (either an ice shelf or sea ice), with wave action inhibited by the ice cover (L.H. King, personal communication, 1981). Little is known of analogous contemporary environments. An ice shelf model would imply sea level not far from its present level, and most probably a rise in sea level from the time of the widespread early till sheet.

The distinctive upward fining sequence from facies 4 through facies 3 to facies 2 in acoustic unit a (Fig. 34) suggests a change from proximal to distal sedimentation environment during the accumulation of acoustic unit a. This may be related to a gradual lifting of an iceshelf off the seafloor, as sea level rose or ice thinned, with sediment supplied from subglacial streams discharging close to the grounding line. The origin of the well stratified acoustic unit b is also poorly constrained. The ponded morphology suggests a bottom-related sediment transport process. The facies thins rapidly seawards. It may represent proglacial marine deposits or may have been subaerial. Although the lower part of acoustic unit b has not been conclusively sampled in the South Shore region, Kontopoulos and Piper (1982) did obtain proglacial mud, sands and gravels for a similar acoustic facies in Kaipokok Bay, Labrador. The acoustic mask apparently due to gas in the southern part of Bull Rock Channel suggests some organic productivity at the time, and may indicate lowered sea level in order to achieve a sheltered basin, or even a lake.

The "late till" marks an apparent minor glacial re-advance that is approximately synchronous with the deposition of acoustic units b and c. It may be synchronous with the Bennett Bay till in central Nova Scotia (Stea, 1982). The unconformity between acoustic units b and c corresponds to the classical late Wisconsinan sea level lowering to –120 m, which has been variously dated at 18 000-20 000 years BP. The apparent glacial advance may be principally a consequence of drawdown of an ice margin that was floating during previous high stand of sea level. Terrestrial bog and lake stratigraphies on the South Shore suggest that ice did not retreat from the present coastline until as late as 13 000 BP (Railton, 1973; Green, 1976; Prest and Grant, 1969). Rising sea level following the grounding that produced the late till may thus have re-established ice shelf conditions near the present coastline, and there may have been little change in position of the ice margin for several thousand years.

Acoustic unit c locally rests unconformably on acoustic units a and b. In shallow water, the unconformity is sometimes channelled, and the unit passes laterally into late till, suggesting a subaerial origin. Acoustic unit c is thus younger than the major lowering of sea level. All attempts to piston core through acoustic unit c nearshore, even where it is thin, have been unsuccessful because of large clasts of Meguma

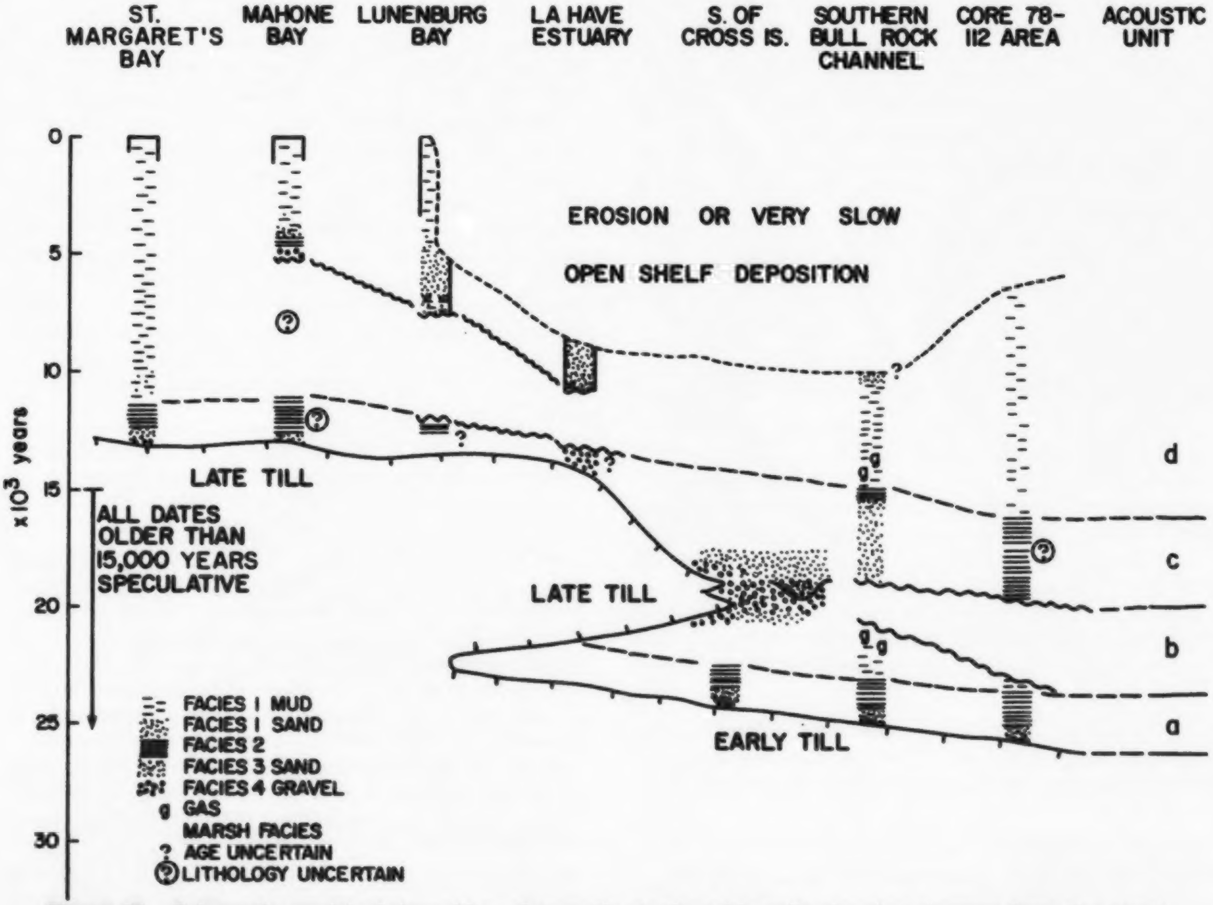

ST. MARGARET'S BAY
MAHONE BAY
LUNENBURG BAY
LA HAVE ESTUARY
S. OF CROSS IS.
SOUTHERN BULL ROCK CHANNEL
CORE 78-112 AREA
ACOUSTIC UNIT
0
5
10
15
20
25
30
x10³ years
EROSION OR VERY SLOW
OPEN SHELF DEPOSITION
LATE TILL
ALL DATES OLDER THAN 15,000 YEARS SPECULATIVE
LATE TILL
EARLY TILL
d
c
b
a
g
?
FACIES I MUD
FACIES I SAND
FACIES 2
FACIES 3 SAND
FACIES 4 GRAVEL
g GAS
MARSH FACIES
? AGE UNCERTAIN
? LITHOLOGY UNCERTAIN

Figure 46. Schematic model of deposition of acoustic stratigraphic units showing changes from the coast seawards. For explanation see text.

Group strata which overlie the unconformity. Offshore the unconformity is planar and is believed to result from coastal planation during transgression following the deposition of the late till.

At the top of acoustic unit c facies 3 is developed, consisting of poorly-sorted muddy gravelly sands with low numbers of shallow water foraminifera. Its origin is unclear. It might have formed by reworking of terrestrial sediments by a rising sea level, reworking of deltaic sediments by a falling sea level, final disintegration of stagnant ice in contact with the sea, or sedimentation as proglacial delta bottomsets.

Facies 3 passes up into facies 2 silts and muds with microfossils suggesting ice margin conditions. This facies probably accumulated by rapid deposition of suspended proglacial sediment. Offshore, it passes into facies 1 muds in the lower part of acoustic unit d. Deposition of facies 2 ceased once sediment runoff was reduced, either as ice retreated from the vicinity of the coastline, or with the disappearance of most ice on mainland Nova Scotia at about 10 000 years. The generally ponded character of this facies suggests waves or currents were active during deposition, although the ice margin itself may have been floating.

It is probable, but not certain, that the initial post-glacial sea level rise was very rapid, reaching at least –20 m around 16 000 BP and was then followed by a fall in sea level to perhaps –40 m before the Holocene transgression. During this initial rapid rise, there would have been little coastal erosion near the present coastline, because of the presence of the ice sheet. However, as sea level rose during the Holocene transgression, there was a period of erosion on the open shelf. This was probably the result of storm-generated longshore currents that could only develop once rising sea level had drowned the offshore shoals which blocked significant longshore movement of water. A continuing rise in sea level would reduce the strength of such currents, thus permitting deposition of acoustic unit d. As the transgression continued, this unit was also deposited in deeper parts of coastal bays and the nearshore zone. In places in the coastal zone, acoustic unit d overlies estuarine sediments of acoustic unit c. This contact is locally unconformable, probably as a result of shore face erosion during coastal transgression.

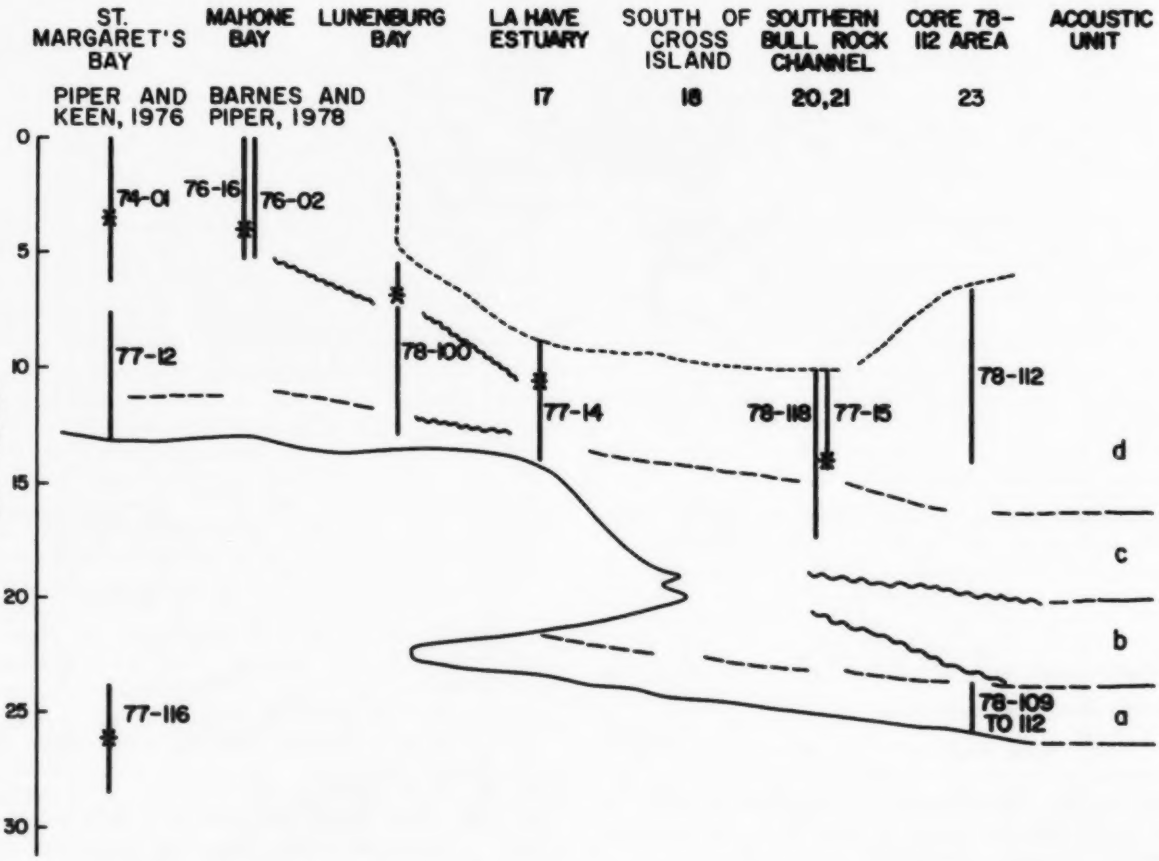

ST. MARGARET'S BAY
MAHONE BAY
LUNENBURG BAY
LA HAVE ESTUARY
SOUTH OF CROSS ISLAND
SOUTHERN BULL ROCK CHANNEL
CORE 78-112 AREA
ACOUSTIC UNIT
PIPER AND KEEN, 1976
BARNES AND PIPER, 1978
17
18
20,21
23
0
5
10
15
20
25
30
x10³ YEARS
74-01
76-16
76-02
77-12
78-100
77-14
78-118
77-15
78-112
77-116
78-109 TO 112
d
c
b
a

Figure 47. Key to location of cores and seismic reflection profiles used in interpreting acoustic stratigraphy. Asterisk indicates radiocarbon date in core. Compare with Figure 46.

SURFICIAL SEDIMENT

Distribution

Figure 48, which shows distribution of surficial sediment, is based on the interpretation of MS26-B (14.25 kHz) and 3.5 kHz echo sounder profiles augmented with bottom samples, following techniques described by King (1967) and Piper and Keen (1976). Lower-frequency seismic-reflection profiles have also been used where no other data are available. The mapped units are defined by grain-size distribution of the sediments.

A wide range of gravelly, sandy and muddy sediments have been sampled. Within small areas, textural analysis shows natural clusters of grain size distribution, which cut across the arbitrary boundaries of established nomenclature schemes, such as that of Folk (1968). Seven such natural clusters were used in mapping St. Margaret's Bay (Piper and Keen, 1976). The boundaries of these clusters, however, vary according to wave exposure and source material, and any classification system that is applicable to the whole coast must be broad.

Three main sediment types are distinguished: muds, sands and gravels. In some areas, mappable subdivisions of these three types have been possible.

Predominantly muddy sediments are restricted to sheltered bays, being most widespread in St. Margaret's and Mahone bays. Muds (unit 5a) (Fig. 48) accumulate in basins, with sandy muds or muddy sands (unit 5b) at basin margins close to major sand bodies. These muds are equated with the LaHave Clay of King (1970).

Predominantly sandy sediments (unit 4), equated with the sand facies of King's (1970) Sable Island Sand and Gravel, are found on beaches and the shore face; and in basins on the innermost part of the shelf (never more than 4 km from shore). In most such basins there is a rapid seaward transition to sandy gravels (unit 3c) or gravelly sands (unit 3a) (seen more clearly in maps of modal grain size distribution, Fig. 49). This boundary is referred to as the 'sand line'. In addition, gravelly sands are seen at the margins of sand basins. The gravelly sediments (unit 3) are equated with the gravel facies of the Sable Island Sand and Gravel.

Muddy gravelly sand (unit 3b) (with more than 10% mud and less than 50% gravel) is widespread in sheltered bays on both basin flanks and deeper shoals. It appears to be a thin veneer of sediment resting on till.

Granulometric analysis

Sable Island Sand and Gravel

Sable Island Sand and Gravel occurs in two distinct geological settings. It is the characteristic sediment of the open shelf and exposed coasts, and also occurs as a veneer on eroded till platforms in shallower water in St. Margaret's and Mahone bays.

On the open shelf, nearshore sands have a modal grain size of around 3.5 phi (Fig. 49; analyses D,F, in Fig. 50). Coarser sediment occurs near bathymetric highs (analysis J, Fig. 50) and on beaches (analysis G, Fig. 50). Coarser sand also occurs near eroding drumlins, as in Port Joli (Fig. 49) where a patch of poorly sorted coarse sand (analysis H, Fig. 50) occurs off a drumlin and is surrounded by very fine sand.

Farther seawards, sands become coarser, with increases in both modal size (analyses C, E, Fig. 50) and, in some areas, in the amount of gravel. Modal sizes as coarse as 1 phi occur off Port Joli (analysis I, Fig. 50). There is an abrupt change at the 'sand line' to gravelly sediments with modal sizes mostly between –3 and –5 phi. The modal sand size immediately landward of the 'sand line' is very variable (Fig. 49), for example being 3.5 phi off Sable River, 2.5 phi off Green Bay and Port Mouton, and 1 phi off Port Joli.

Gravels seaward of the sand line are commonly very well sorted (e.g. analysis 1 in Fig. 51), in contrast to the gravels and sandy gravels at the edge of sand-filled basins landward of the 'sand line' (e.g. analyses 3 and 8, Fig. 51). Where Sable Island Sand and Gravel bodies lap onto till or bedrock, cobbles form a surface armour. *Lithothamnium* crusts suggest the cobbles are only rarely turned over by storms.

A plot of skewness against sorting for the sands (Fig. 51) shows several distinct fields. Most open shelf sands with modes from 3.5 phi to 1 phi are moderately sorted and negatively skewed, as illustrated by the sands off Port Joli and Port Hebert, suggesting that winnowing and removal of very fine sand and silt has occurred. However, in Green Bay, fine sands with a 2.5 phi mode are slightly positively skewed, suggesting that the enclosed shape of the bay inhibits complete removal of very fine sand and silt. In nearshore very fine sands, with a 3.5 phi mode but up to 25% poorly sorted silt (e.g. off Sable River), there is strong positive skewness and poor sorting, both increasing with silt content. Positive skewness is also found in the Port Joli coarse sands derived from drumlin erosion, in which there is a fine tail transported in from the nearby shelf.

Letson (1980) has made a detailed analysis of the Sable Island Sand and Gravel facies developed on eroded till platforms and adjacent upper-basin margins in western Mahone Bay. On beaches at the foot of eroding till cliffs, boulders and cobbles with a sand-gravel matrix rest on an eroded till platform. Similar sediments extend offshore across much of the platform. Cores of these sediments are inversely graded, with matrix content increasing with depth. Seawards, cobbles become common as the number of boulders decreases, and a veneer of loose mud blankets the sea floor in fair-weather conditions. Near the platform margin, there is usually an abrupt change to finer sediment, usually in a 5-30 cm thick graded bed of gravel passing up into sand and then mud. Most of these finer sediments fall within map unit 3a (gravelly sand) of this study (Letson, 1980, Fig. 6.6). Detailed grain size analysis both of the matrix between the cobbles and boulders and of the cobble-free sediments on the platforms and upper basin margin shows that almost 80% of the sediment is polymodal (Letson, 1980, Fig. 6.15), with some unimodal coarse and fine sands on the outer platform and upper basin margin. Boulder matrix samples have a gravel or very coarse sand mode and a coarse to fine sand mode. Upper basin margin samples have gravel to very coarse sand, fine to very fine sand, and medium to fine silt modes. Skewness changes across the platforms from negative to positive values as depth increases (Letson, 1980, Fig. 6.18).

The polymodal sediments are probably a result both of highly variable energy conditions (ranging from fair weather to severe storms) and of the influence of large lag boulders left as the till cliffs have retreated. The fine silt modes probably represent fair weather deposits. Coarse silt (4-5 phi) modes are rare: this sediment size appears to bypass the platforms and accumulate in basins during storms, yet is too coarse to be transported during fair weather conditions. The negative skewness in shallow water reflects winnowing; the positive skewness in deeper water on the upper basin margin reflects silt and clay deposition.

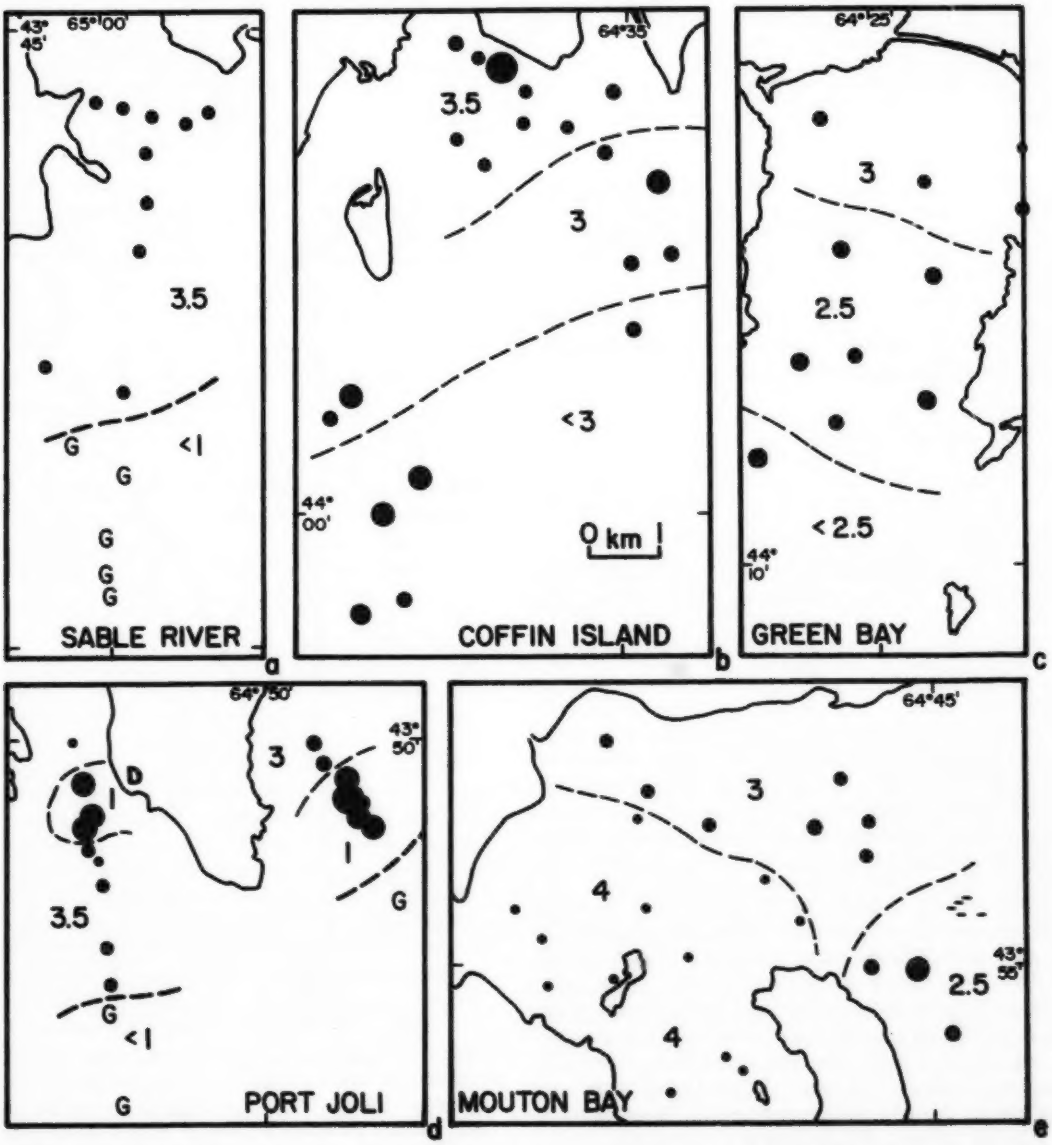

43° 45'
65°00'
3.5
G
<1
G
G
G
G
SABLE RIVER
a
64°35'
3.5
3
<3
44° 00'
0 km 1
COFFIN ISLAND
b
64°25'
3
2.5
<2.5
44° 10'
GREEN BAY
c
64°50'
43° 50'
3
D
1
1
G
3.5
G
<1
G
PORT JOLI
d
64°45'
3
4
4
43° 55'
2.5
MOUTON BAY
e

Figure 49. Series of maps (all to same scale) showing modal grain size of surficial sands and gravelly sands, in (a) Sable River, (b) Coffin Island region, (c) Green Bay, (d) Port Joli, and (e) Mouton Bay. The position of the 'sand line' (transition from sand to gravel) is shown for Sable River and Port Joli. G = sorted gravel; D = eroding drumlin.

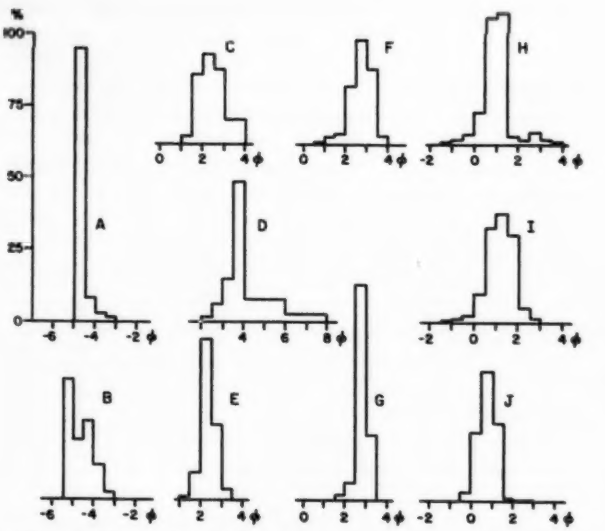


Figure 50. Selected grain size analyses (in phi units) from Sable Island Sand and Gravel. A,B: sorted gravels south of Port Hebert; C,D: sands, Port Mouton; E,F: sands, Green Bay; G: beach sand, Crescent Beach, Green Bay; H: coarse sand off eroding drumlin, Port Joli; I: coarse sand off Cadden Beach, Port Joli; J: coarse nearshore sand near Coffin Island.

LaHave Clay

The typical nearshore developments of LaHave Clay (Fig. 53) contain less than 5% fine sand and have more silt (50-60%) than clay (45-50%). They are thus substantially siltier than the type LaHave Clay of the Scotian Shelf, described by King (1967) and resemble peripheral facies found on the Scotian Shelf. At the margins of basins, the LaHave Clay contains increasing quantities of both fine sand and silt (Piper and Keen, 1976, Fig. 12). Larger basins, such as the central basin of St. Margaret's Bay, contain muds with less than 1% sand; small basins close to till sources (such as the small basins in southwestern Mahone Bay studied by Letson, 1980) contain at least 3% sand in basin-centre muds.

Letson (1980) studied granulometric changes from the margins to centres of basins in southwestern Mahone Bay. Basin margin muds have coarse silt modes, fining towards the basin floors where muds are either unimodal (5-7 phi mode) or bimodal with an additional 4-5 phi mode (Letson, 1980, Fig. 9.2). Silt to clay ratio decreases from 2.2 to 1 on the lower basin margin to 1.8 to 1 on the basin floor. Some mud accumulates on the Sable Island Sand and Gravel on the outer part of eroded drumlin platforms under fair weather conditions. During storms, this sediment is completely resuspended by shoaling waves, and the basinward fining of the LaHave Clay probably reflects progressive suspension fallout of sediment.

Sedimentary structures

Few cores include the sand facies of the Sable Island Sand and Gravel, and most of these were disturbed during coring operations. The two best samples are 78-137 in Gull Bay and 77-15 off Cross Island.

Core 78-137, in 44 m of water, consists of 110 cm of sand resting on 40 cm of shelly gravel. The entire core shows a gradual upward decrease in grain size, from gravel through very coarse and coarse sand to medium and fine sand. No internal bedding structures were seen. The base of the core is about 5000 years old (Table 1), and the decrease in grain size might reflect the 10-15 m rise in sea level over this time. However, the present distribution of modal sizes (Fig. 49) suggests that rising sea level should result in upward coarsening, and it is possible that the entire 1.5 m sequence was remobilized during a storm.

The top 105 cm of core 77-15 consists of five or six slightly graded beds of silty sand up to 30 cm thick with 4 phi or 4.5 phi modes. The coarsest sand grains are 1.5 phi. These graded beds are poorly sorted and lack tractional sedimentary structures: they thus appear to be suspension fall-out deposits

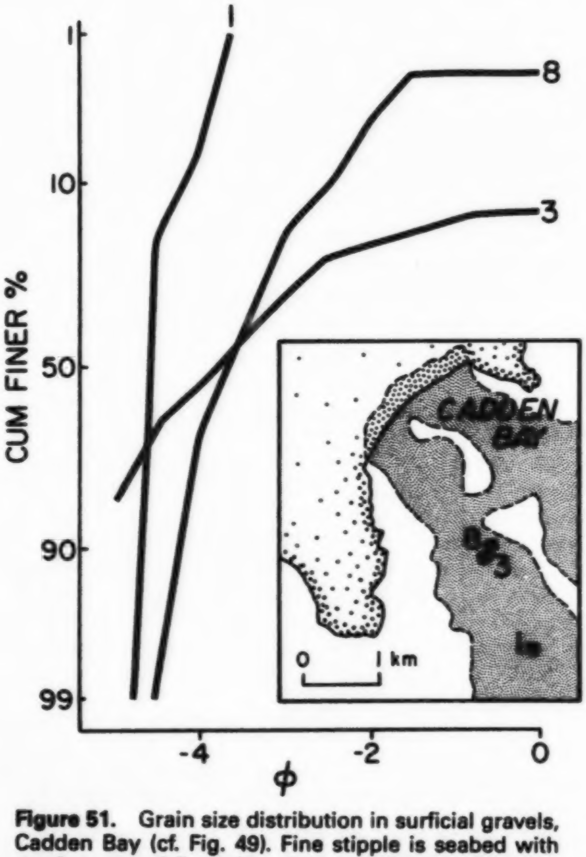


Figure 51. Grain size distribution in surficial gravels, Cadden Bay (cf. Fig. 49). Fine stipple is seabed with sand or gravel (Location shown as Cadden Beach in Fig. 3).

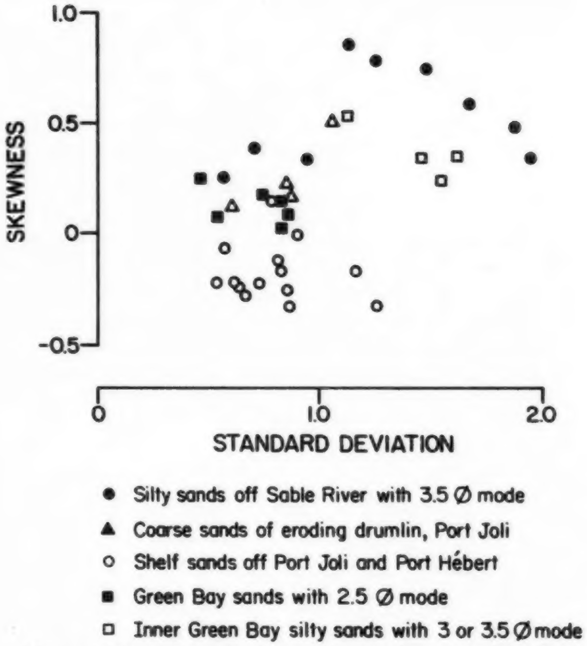


Figure 52. Plot of skewness against sorting for selected sand analyses from the Sable Island Sand and Gravel.

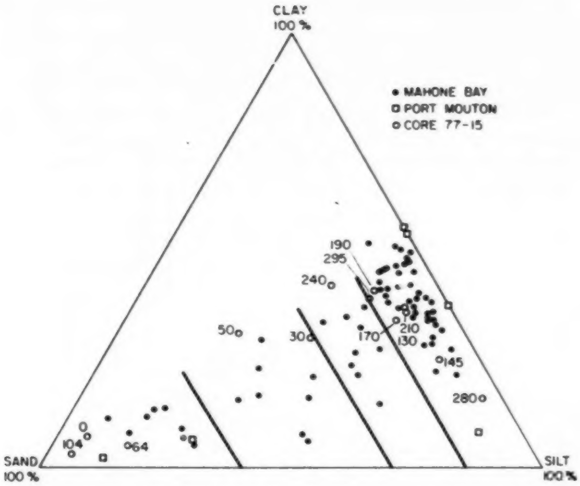


Figure 53. Grain size distribution in acoustic unit d, Sable Island Sand and Gravel and LaHave Clay. Numbers are depths in core 77-15 in centimetres.

similar to those described by Kontopoulos and Piper (1983) from the southern margin of Emerald Basin. Core 78-98 from Lunenburg Bay contains several 5-10 cm beds of alternating medium and fine sand, which may also represent storms.

Cores from the LaHave Clay are highly bioturbated, but show distinct silty laminae (Piper and Keen, 1976, Fig. 13). These have been investigated in detail by Letson (1980) in Bella Basin, Mahone Bay, and the subsequent discussion is based largely on his work. Typical laminae consist of thin (≈2 mm) subhorizontal sandy silts in sets less than 2 cm thick, separated by several centimetres of mud showing a gradual upward decrease in sand content (Letson, 1980, Fig. 7.4). Basin floor muds contained 3-5% sand, while silty laminae contained 6-12% sand. On the lower basin margin, muds contained as much as 25% sand and silty laminae as much as 50% sand. The coarsest sands in the laminae are slightly coarser than the coarsest sands in the interbedded muds (Letson, 1980, Fig. 7.5). Individual sets of laminae can be correlated in closely spaced cores for up to 2 km across the floor of Bella Basin (Letson, 1980, Fig. 7.7). The spacing of the sets of laminae suggests a recurrence period of tens of years, and they would seem to represent massive storm resuspension of upper margin sediments, and suspension fallout into the basin. The absence of winnowed horizons suggests that storm waves do not significantly disturb the basin floor.

These silty laminae are not restricted to small nearshore basins. They are abundant in LaHave Clay from the central basin of St. Margaret's Bay, Halifax Harbour (Delure, 1983), the open shelf south of Lunenburg (core 78-112, Fig. 36), and the southern margin of Emerald Basin (Kontopoulos and Piper, 1983).

Gravel petrology

Simple measurements were made to assess how petrology of the gravel fraction of till varies in different parts of the Lunenburg drumlin field, and to determine whether coastal processes modify the relative proportions of different rock types. Samples were collected from several till cliffs and adjacent pebble beaches (Fig. 32).

Large samples (several kilograms) were taken and sieved to separate the fractions coarser than –2 phi, and from –2 to –1 phi (Fig. 54). In general, this yielded 600 to 2000 clasts in the coarser fraction and 10 000 to 50 000 in the finer fraction. These were then split further, and from 250 to 650 clasts were counted.

The most striking feature is the variability of the tills, despite the large samples used. As a result, it is difficult to assess changes from till to beach. Beaches have slightly lower shale or slate content than adjacent till, but this is only pronounced in sample 3 (Fig. 55) where both till and beach consist almost entirely of Meguma rock fragments. The concentration of upper Paleozoic-Triassic sedimentary rocks is lower on the beaches, probably because of abrasion of the softer lithologies. There is an apparent increase in the proportion of granites and other igneous rocks on the beaches compared with tills. Although probably in part due to the hardness of these rocks, it may also be that these lithotypes are easier to recognize in a polished beach sample than in a dirty till.

None of the above differences between beach and till gravels is very pronounced, suggesting that the petrology of nearshore gravels is a reliable indicator of the petrology of parent till. This is in contrast to Grant (1963), who found a 10% loss of granite and a 70% loss of sandstone on an exposed beach at Petpeswick Head, about 35 km east of Halifax. Because of the inhomogeneity of the parent tills and the variability in wave energy on beaches, however, a more sophisticated analysis and more extensive sampling program are required to confirm the preliminary findings.

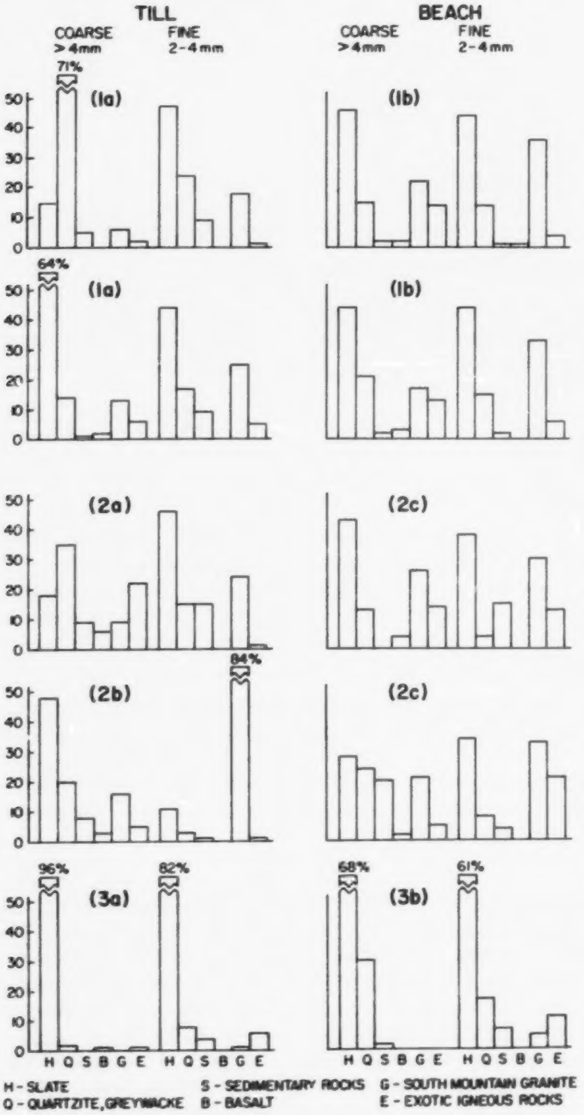


Figure 54. Comparison of lithologic composition of gravel samples from tills and beaches, Lunenburg Bay. See Figure 32 for location of samples.

Mineralogy of heavy minerals

The heavy mineral content of the 2.5 to 3 phi fraction of a representative suite of 35 samples from the entire study area (Table 4, Fig. 55) has been counted by a single operator (A. E. Aksu). An additional 10 samples from St. Margaret's Bay, 8 from Mahone Bay, 11 from Green Bay, 23 from Port Mouton and 22 from Port Hebert have been counted by others. Results are summarized in Figures 55 to 61.

Previous work on heavy minerals of the South Shore has been done by Nolan (1963) who sampled the beaches, and by Nielsen (1976) who studied tills of mainland Nova Scotia. Both found marked variations along the South Shore, which Nielsen was able to relate to the bedrock sources of the till. Nielsen used factor analysis to recognize natural assemblages of heavy minerals. As our data are not strictly comparable, we

Table 4. Heavy minerals

Sample Number	% Heavy Minerals, excluding micas, chlorite, altered grains						
	op	px	res	gt	staur	ep	and
506-72-106	16.6	33.3	33.3	14.6	2.1	0	0
108	14.5	32.5	31.3	20.5	0	1.2	0
78-005-128	28.9	39.8	8.4	13.3	0	9.6	0
145	27.3	19.7	19.7	29.6	0	3.6	0
143	59.3	22.1	2.0	12.1	0	4.5	0
126	63.4	19.7	4.9	9.2	0.7	2.1	0
504-76-145	39.6	42.2	4.8	13.4	0	0	0
16	47.0	36.0	0.5	16.5	0	0	0
19	28.0	65.3	6.7	0	0	0	0
20	72.0	23.2	2.4	2.4	0	0	0
54	43.8	53.9	2.3	0	0	0	0
62	30.4	49.3	4.3	13.0	0	2.9	0
96	54.3	40.0	5.7	0	0	0	0
97	46.7	43.4	1.3	5.3	1.3	1.3	0.7
100	48.2	31.7	2.0	18.1	0	0	0
104	56.9	34.5	2.6	6.0	0	0	0
127	34.2	63.9	1.0	1.0	0	0	0
134	38.6	41.4	8.6	8.6	0.7	2.1	0
151	53.2	35.5	3.8	4.8	0	2.7	0
158	42.1	43.2	2.1	10.5	0	2.1	0
163	31.8	63.5	4.7	0	0	0	0
237	48.6	37.9	2.1	10.7	0	0.7	0
238	43.3	48.0	5.4	3.4	0	0	0
504-77- 14	37.3	51.6	5.6	4.8	0	0	0.8
21	62.6	30.8	0	5.5	0	1.1	0
32	59.9	30.5	4.3	3.5	0	1.4	0.4
46	59.4	30.2	4.7	2.8	0	2.8	0
509-77- 92	57.5	33.6	9.0	0	0	0	0
94	79.0	13.7	2.7	4.6	0	0	0
78-005-133	62.7	15.4	5.0	9.2	0.6	6.2	0.9
141	51.4	17.1	0.8	24.3	4.0	2.4	0
513-78- 24	42.9	21.4	0	21.4	5.3	8.9	0
41	19.8	29.3	18.9	19.8	7.5	4.7	0
45	52.0	8.9	2.2	28.3	6.3	2.2	0
48	37.4	42.1	5.8	3.5	0	11.1	0
54	31.2	1.5	5.3	50.6	10.6	0.8	0

op = opaque minerals; px = pyroxene; res = tourmaline, zircon, apatite, rutile and sphene; gt = garnet; staur = staurolite; ep = epidote; and = andalusite.

have used his assemblages only in a semi-quantitative fashion. Nolan's data show that andalusite, staurolite, garnet and tourmaline are minor components with a distinctive distribution. Nielsen found that heavy mineral content of tills was related to a southward flow of ice over bedrock with distinctive heavy minerals. Far-travelled drumlin till was mineralogically distinct from local basal till.

Almost all the heavy mineral samples from the South Shore are rich in opaque minerals and pyroxene. In addition, many samples contain large amounts of mica and chlorite, but because the separation of these minerals is difficult to duplicate, they have been excluded from counts. Garnet is abundant in some samples. Other minerals present include tourmaline, zircon, apatite, rutile and sphene (grouped together in Table 4 as resistate minerals) and the metamorphic minerals staurolite, andalusite and epidote.

Almost all samples, except those from southwest of Port Mouton, are dominated by opaques and pyroxene. This suggests that red drumlinoid till, similar to the Lawrencetown till found in the Lunenburg drumlin field, is the principal source for the heavy minerals. The salient geographic variations in other heavy minerals along the South Shore are:

(i) samples from St. Margaret's Bay, particularly those from offshore, are rich in apatite and epidote, and most contain relatively few opaques and pyroxene;
(ii) samples from Port Mouton to Sable River are rich in staurolite (and also contain significant epidote);
(iii) garnet is common in samples from the St. Margaret's Bay area, off Mahone Bay, on the northeast side of Lunenburg Bay, offshore from Liverpool Bay and from Port Mouton to Sable River;
(iv) samples from Green Bay and Liverpool Bay are particularly rich in opaques.

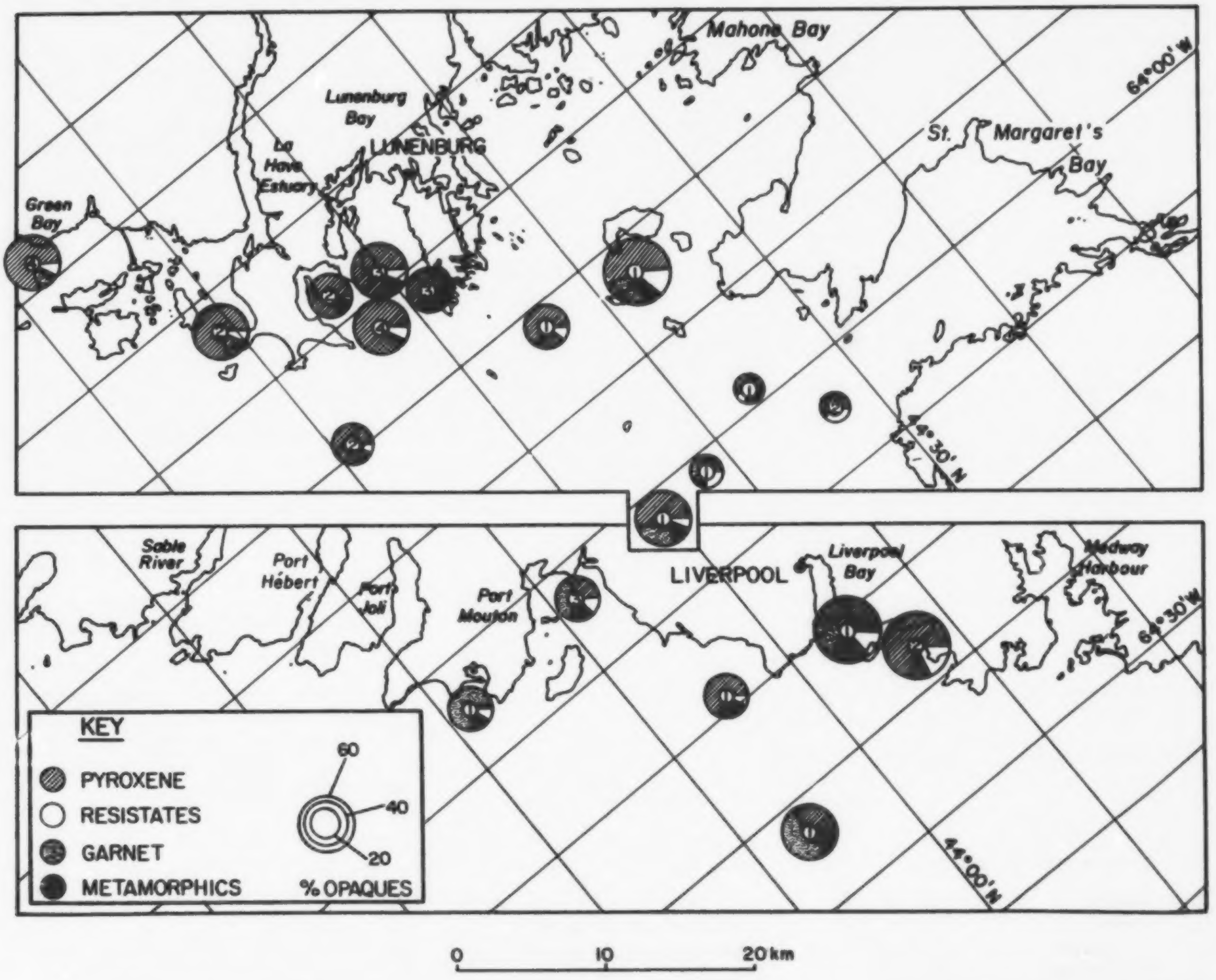

Mahone Bay
Lunenburg Bay
LUNENBURG
La Have Estuary
Green Bay
St. Margaret's Bay
64°00'W
44°30'N
Sable River
Port Hébert
Port Joli
Port Mouton
LIVERPOOL
Liverpool Bay
Medway Harbour
64°30'W
44°00'N
KEY
PYROXENE
RESISTATES
GARNET
METAMORPHICS
60
40
20
% OPAQUES
0
10
20 km

Figure 55. Regional variation in heavy mineral assemblages in 2.5 to 3 phi sand fraction of Sable Island Sand and Gravel, South Shore. Numbers indicate number of samples averaged for pie diagram.

These distinct geographic variations in the heavy mineral distribution of nearshore samples along the coast correspond to variations noted by Nielsen (1976) in onshore tills. This suggests that nearshore sand is derived from erosion of till either at the present coastline, or along earlier coastlines farther offshore, and has not been moved in significant amounts in a longshore direction in the nearshore zone.

Because offshore sediments are sparse and gravelly, it is difficult to obtain good representative samples and few are available. The data are thus insufficient to evaluate properly possible longshore transport of sediment. Samples offshore from St. Margaret's Bay, like nearshore samples, are rich in garnet, epidote and resistant minerals, but are also preferentially enriched in opaques and pyroxene compared with nearshore samples. Opaques and pyroxene characterize the Lunenburg area to the southwest, so these minerals may have been introduced by longshore transport. Alternatively, tills farther offshore may have been richer in the opaque and pyroxene component, continuing the trend observed by Nielsen on the Sambro peninsula (Piper and Keen, 1976). Likewise, the one sample offshore from Liverpool contains abundant garnet and staurolite, typical of sediments in the Port Mouton area. In this region, a seaward increase in these minerals in source tills is less probable. These offshore data are consistent with up to 30% of the offshore sand having

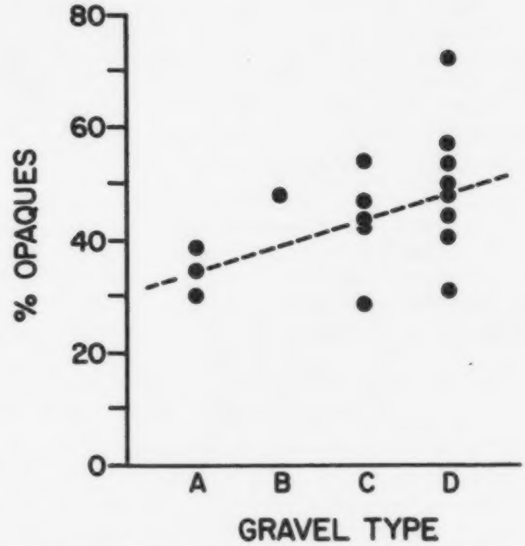


Figure 56. Plot of per cent opaque minerals (as per cent of total 2.5 to 3 phi heavy minerals) against gravel type for Lunenburg Bay and vicinity. Gravel type: A = slate only, B = slate and Meguma sandstone, C = shale, Meguma sandstone, rare exotics, D = principally exotics. (Compare with Fig. 32).

Table 5. Clay mineralogy

			Percentage			
Sample Location	Number	Lithofacies	Illite	Chlorite	Kaolinite	Montmorillonite
Marine Sediments						
Port Mouton	79- 22-210/212	1	77	18	1.3	3.1
	79- 23-105/107	1	77	14	4.0	4.8
	23-423/426	1	82	12	4.0	1.7
	79- 26-15/17	1	81	15	2.3	1.0
South of Lunenburg	78-112-108/110	2	67	16	14	2.4
	140/142	2	63	19	15	2.6
	200/202	2	70	19	8.8	2.6
	290/292	2	66	19	11	3.6
	305/307	2	65	23	8.9	2.6
	325/327	2	70	18	10	2.0
	77-15 - 30/ 31	1	65	27	5.5	2.5
St. Margaret's Bay	77-12 - 4/ 6	2	74	12	9	5
	141/143		87	5	4	4
Bedford Basin	79-01 -387/391	2	70	22	8	tr
	420/424	2	63	22	12	3
	468-472	2	67	19	10	4
	479/482	2	70	25	5	0
Tills (samples from Nielsen, 1976)						
Bedford	EN-222	T1	58	26	10	6
LaHave	EN-260	T1	83	10	6	1
Bridgewater	EN-262	T1	34	29	12	25
Port Medway	EN-493	T1	68	18	13	1

Mineralogy determined by x-ray diffraction of <2 μm size fraction. Percentages calculated using diagnostic peaks and weighting factors of Piper and Slatt (1977).

moved parallel to the coast for up to 20 km. There is no evidence for significant longshore transport over greater distances.

The detailed local studies provide further information on the sources and movement of heavy minerals. Lunenburg Bay data (Table 4) show considerable heterogeneity, most easily seen in the variations in opaques and garnet. This heterogeneity is not due to sampling error. If as few as 100 grains are counted, there is a 4.8% error at the 95% confidence level for a mineral present in only 5% abundance; there is still a 2.6% error if 300 grains are counted. Data in Table 4 show that the variability exceeds these limits and thus cannot be explained solely by counting error. Other errors may be introduced by shape, size or density segregation while preparing a mount; however replicate mounts from the same mineral separation show differences in heavy mineral assemblage within the range of counting error. The gravel component of Lunenburg

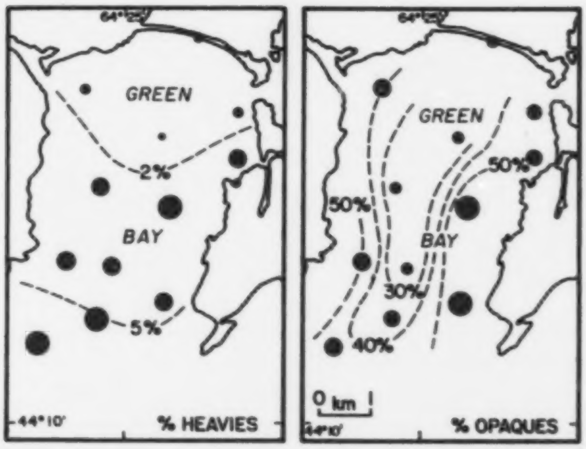


Figure 57. Green Bay. Left: per cent heavy minerals in 2.5 to 3 phi size fraction. Right: opaque minerals as per cent of total heavy minerals (for modal grain size, see Fig. 49).

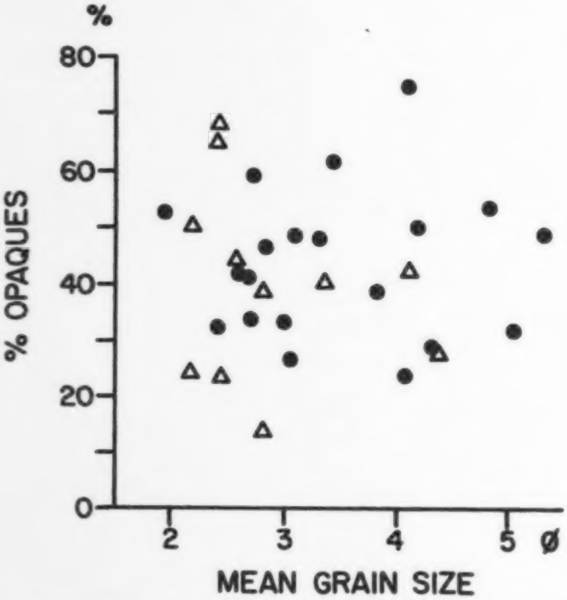


Figure 58. Plot of opaque minerals as percentage of total heavy minerals (2.5 to 3 phi) against mean grain size for Green Bay (triangles) and Port Mouton (circles) samples. (Error limits at 95% level for most samples are ±3%.)

Table 6. Rates of cliff retreat

(a) *By Ground Survey*

Location	Rock type	First Surveyed	Last Surveyed	Rate (m/a)
Hartlen Point	till	1972	1979	1.3
Mahone Bay				
East River Point	granite	1975	1978	0
Covey Point	gravelly till	1975	1978	0.25
Mason Island	till	1976	1978	1
Rous Island	till	1976	1978	0.25

(b) *Other Methods*

Location	Rock type	Method	Rate
Kings Bay,			
N. drumlin	till	air photos, field check	0.1
S. drumlin	till	air photos, field check	0.4
Hartling Bay,			
E. drumlin	till	air photos, field check	1.5
#2 drumlin	till	air photos, field check	1.2
#3 drumlin	till	air photos, field check	0.3
W. drumlin	till	air photos, field check	0.1
East side Port Joli	till	air photos 1929-1976	0.1

Bay sediments appears relatively immobile, and ranges from exclusively slate clasts to predominantly 'exotic' clasts of granite and upper Paleozoic sediment derived from red drumlinoid till. There is moderate correlation between heavy mineral assemblage and the gravel petrology of the same or immediately adjacent samples (Fig. 56). This suggests that although fine sand is more mobile than gravel, the character of the heavy mineral assemblage depends on the character of the immediately adjacent till.

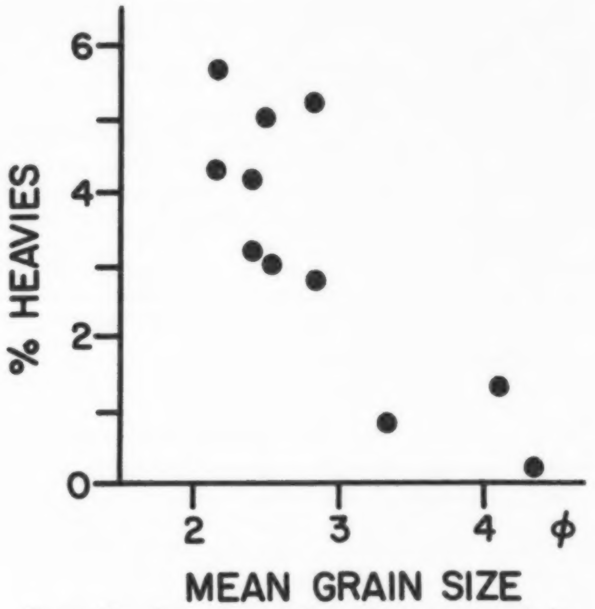


Figure 59. Plot of percentage of heavy minerals in total sand sample against mean grain size (phi units) for Green Bay.

The Green Bay samples (Fig. 57) are variable even though there are no significant contemporary sediment sources. There is no simple relationship between mean grain size and mineralogy (illustrated, for example in Fig. 58). There are some regular trends with water depth and geographic location. There is a gradual northward (shoreward) decrease in the percentage of heavy minerals in the 2.5-3.0 phi fraction (Fig. 57), which reflects a gradual decrease in modal grain size northwards (Fig. 49, 59). Since heavy minerals are hydrodynamically equivalent to light minerals 0.5 to 1.5 phi sizes coarser, the greatest relative abundance of heavy minerals in the 2.5 to 3.0 phi size fraction will be found in sands with a mode between 1.5 and 2.5 phi. Waves may also sort minerals by density and shape.

In the area around Port Mouton there is slow erosion of low drumlin cliffs locally, but the rate of contemporary sediment supply is very low. Heavy mineral distribution is again very inhomogeneous (Fig. 60) and shows little obvious dependence on grain size (Fig. 58) or geographic location. However, if selective wave transport is an important process, then the bathymetry of Mouton Bay could lead to irregular distribution patterns. Most of the source tills contain no pyroxene (Nielsen, 1976) but locally there must be a significant pyroxene source since Nolan (1963) found 50% pyroxene on Port Mouton beach. Pyroxene distribution in marine sediments is most irregular.

In the Port Hebert region, samples are rich in garnet and staurolite, and most contain 5-15% pyroxene. Sands that texturally appear to be derived directly from eroding till cliffs have similar heavy mineral composition to tills (Fig. 61). Once again, heavy mineral distribution is very heterogenous, with no clear controls on mineral type.

Much of the observed small scale variability in distribution of heavy minerals thus appears to be real. This implies that great care must be exercised in interpreting regional distributions of heavy minerals. It suggests that either the primary distribution of heavy mineral supply (from till, or

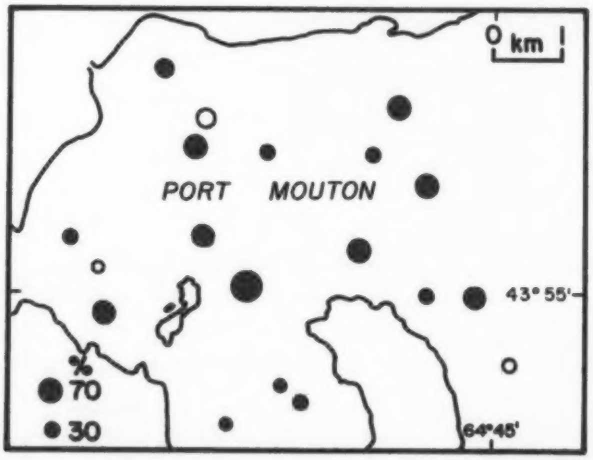


Figure 60. Opaque minerals as percentage of total heavy minerals for Port Mouton. Open circles – abundant staurolite (for modal grain size, see Fig. 49).

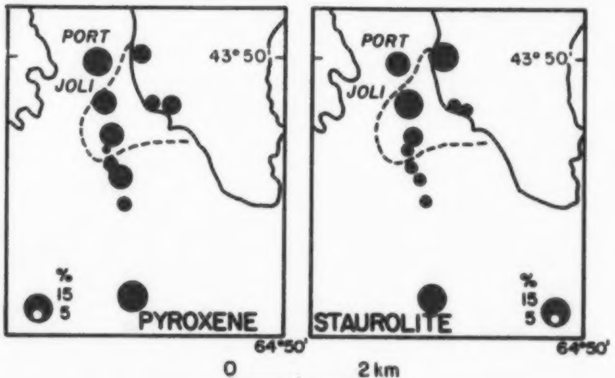


Figure 61. Pyroxene and staurolite as percentage of total heavy minerals for Port Joli region. (For modal grain size, see Fig. 49). Dashed line shows limit of coarse sand derived from erosion of drumlins.

other sources) is very inhomogeneous, or that if there is subsequent sediment movement or mixing, this must be accompanied by heterogeneous sorting processes. Thus while there is geomorphological evidence for late Holocene landward transgression of nearshore and beach sediments, selective concentration of heavy minerals in the spatially inhomogeneous transgressing beach and nearshore environments may account for much of the observed variability.

Clay mineralogy

The mineralogy of the less than 2 μm size fraction of muds has been determined semi-quantitatively by x-ray diffraction (Table 5) following methods outlined by Piper and Slatt (1977) (but without carbonate and iron oxide removal). The clays consist principally of illite, with lesser chlorite. Kaolinite is variable, but reaches 15-20% in the area of the Lunenburg drumlin field. Montmorillonite is present only in very small amounts. Unfortunately, chlorite peaks tend to overlap both montmorillonite and kaolinite; therefore their quantification is imprecise so that subtle abundance variations cannot be used to identify mixing from different sources.

In general, within any one coastal sector, clay minerals in both contemporary and early Holocene muds are similar to those in adjacent tills (G. Camp, personal communication, 1983). The tills consist predominantly of illite and chlorite, but red tills of the Lunenburg drumlin field contain up to 15% kaolinite and minor montmorillonite and other expandable clays.

Surface textures of sands

The evolution of surface textures on sand grains derived from tills was investigated by Urquhart (1976) in Kings and Hartling bays. Quartz grains between 0 and 1 phi were examined by scanning electron microscope. Tills contain angular grains with characteristic glacial features such as parallel striae and conchoidal fractures. About 20% of the grains have prominent diagenetic features such as silica plastering and solution/precipitation, almost unmodified by glacial features. Many of these grains are well rounded, and were probably derived from friable upper Palaeozoic and Triassic sandstones. Small v-shaped and curved gouges typical of subaqueous environments (Krinsley and Doornkamp, 1973) are very rare in tills, but are common in beach and nearshore samples (Fig. 62). No significant differences were detected with distance offshore, except that curved gouges are rare in beach sands. Neither were there differences between the two bays even though the sediment in Kings Bay must be considerably older than that in Hartling Bay, since it lacks a contemporary source. One unexplained feature is that grains with diagenetic characters are particularly common in the sample farthest offshore.

A large number of grains, therefore, would have to be examined to make inferences on the duration and intensity of subaqueous processes following drumlin erosion.

Evolution of contemporary sediment

As a result of the work of Letson (1980) in Mahone Bay, the evolution of contemporary sediment is best understood in the sheltered bays with abundant drumlins in the eastern part of the study area. Here sediment is derived almost exclusively from reworking of eroded till. Wave erosion of till cliffs leads to the development of a wave-cut platform, veneered by boulders and cobbles, that serves to dissipate wave energy. Some sand is transported in the coastal zone to the sheltered lee sides of the islands. Both sand and mud also accumulate under fairweather conditions near the outer edge of the plat-

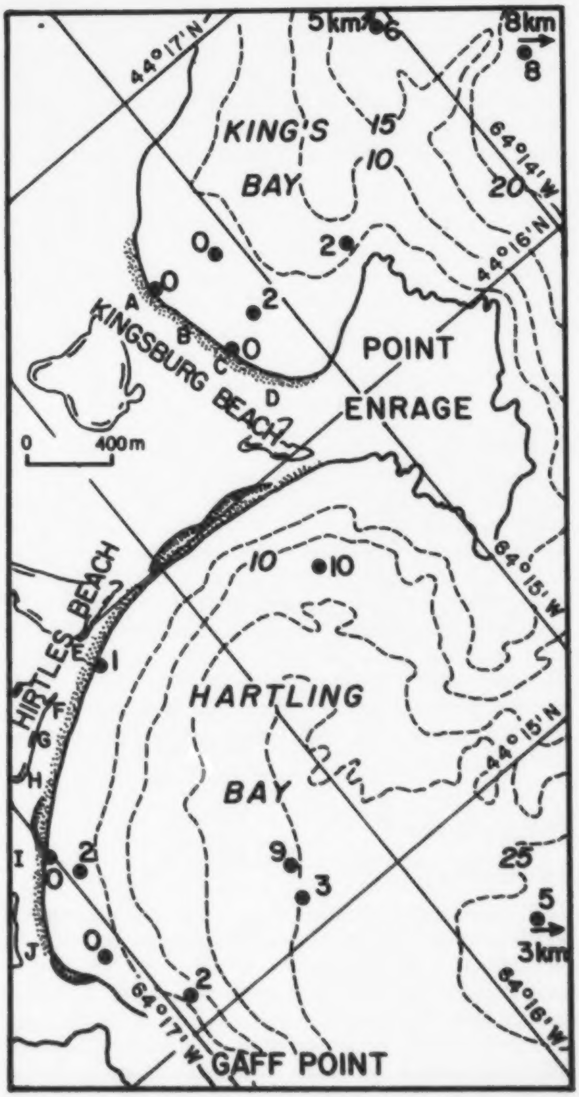


Figure 62. General map of Kings and Hartling bays, showing bathymetry (contour interval of 5 m), eroding drumlins (hachured), beach profiles A to J (see Fig. 64), and number of sand grains (out of 20 per sample) showing curved gouges in SEM micrographs.

forms and on the upper basin margin. Storm resuspension of this sediment leads to very episodic deposition of laminated silts and muds from suspension fall-out in the basins. The storms also produce inverse graded beds on the platforms, and varying intensities of storm conditions lead to polymodal sediments on the platforms. In the case of Lunenburg Bay, the correlation of heavy mineral assemblages with nearby lag gravels suggests that most sand is only dispersed over short distances.

In the more open bays in the western part of the study area, sandy sediments predominate. The paucity of drumlin sources of sand, the seaward changes in modal size, and the evidence for dispersal of some heavy minerals (e.g. pyroxene at Port Mouton) all suggest substantial mobility of sand. Winnowing of very fine sand and silt occurs in all but the most sheltered bays. Yet the spatial heterogeneity of heavy mineral assemblages and their variation in a northeast-southwest direction suggest that the total distance of sand transport is small, and mostly restricted to onshore-offshore movement.

The seaward limit of sorted sands at the 'sand line' marks the transition from predominantly onshore-offshore sediment transport of the nearshore zone to the predominantly longshore transport of the inner shelf (Swift, 1976). The 'sand line' thus represents the seaward limit of the influence of islands and shoals in blocking major longshore movement of water. The abrupt coarsening of grain size suggests a sudden increase in shear stress seaward of the 'sand line', and heavy mineral distribution supports an easterly longshore transport of sand.

There is little evidence concerning the role of storms in these sandy and gravelly sediments. The landward fining of modal sand size suggests that dissipation of large storm waves in shoaling water has a greater influence on sediment distribution than the increasing influence of small waves as water depth decreases. Storm graded sand beds, tens of centimetres thick, suggest much greater sediment flux on the inner shelf than in the sheltered bays. If core 78-137 (Gull Bay) does indicate that over a metre of sand can be reworked in a single storm, then longshore sand transport rates are probably much greater than originally estimated from the limited heavy mineral data.

THE COASTLINE

Introduction

Two contrasting coastal zones occur within the South Shore study area. West of Cape LaHave, the shoreline is irregular and rocky with local large sandy beaches. East of Cape LaHave, the coastline is much more deeply indented, bedrock shoreline is less common, and eroding drumlins and associated poorly sorted beaches are common. Munroe (1982) has made a systematic study of the coastline. In the present study, the coast has been investigated as an area interacting with nearshore sediments. The principal coastal types are described below.

Bedrock coast

This is developed on both granite and Meguma Group bedrock, with either low cliffs or gentle slopes into the sea. Cobble pocket beaches are common. The rate of coastal retreat is very slow, and bedrock coast is not a significant sediment source.

Till cliffs

Much of the coast east of Cape LaHave forms cliffs of drumlinoid till (Fig. 63). In sheltered areas these are vegetated and appear stable, but in exposed areas are steep and are eroding rapidly.

Cliff erosion takes place by a combination of marine and subaerial erosion. During storms, waves undercut the base of the cliffs. This process is probably very episodic. On the southwest coast of Nova Scotia, Grant (1976) recorded 10 m retreat during a single storm on a cliff that had otherwise appeared stable for many years. Subaerial erosion proceeds through gullying by runoff, flow of mobile debris during spring thaws, and landsliding.

Rates of cliff erosion have been estimated from sequential cliff top positions from air photographs or ground surveys (Table 6). Long term monitoring of cliff retreat is continuing. Although not the sole determining factor, fetch is a useful indicator of erosion rates. Cliffs fully exposed to the open sea retreat at rates of 1 to 1.5 m/a, whereas cliffs fully exposed to fetch lengths of 2-5 km retreat at around 0.25 m/a. As till cliffs retreat, the wave cut platform widens and dissipates an increasing amount of wave energy, so that cliff retreat progressively slows. The cliff face becomes less steep as subaerial erosion predominates over marine erosion. Till cliffs with a bedrock footing retreat much less rapidly, and erosion is principally by subaerial processes.

On slowly eroding drumlin coasts in areas that freeze over in winter, boulders released from the till are concentrated in the intertidal zone by winter ice, to form a resistant boulder armour.

Beaches

Three main types of beach are distinguished: shingle beaches; poorly sorted beaches fed by actively eroding drumlins; and sandy beaches, with little or no active sediment supply, that are usually backed by sand dunes. Many of the beaches enclose lagoons, and evidence of continuing sea level rise and coastal retreat is widespread. Bowen (1976) made detailed studies of Cadden, Summerville and Crescent beaches (Fig. 3). On these beaches occasional storms cause extensive washover, and tidal channels allow rapid lagoonal sedimentation, leading to the overall retreat of beaches.

Steep shingle beaches, backed by a rocky shore or lagoon, are common on the more exposed coastlines, especially those with little present sediment supply from drumlins. Beaches with actively eroding drumlin sources are generally poorly sorted, with gravelly sand and boulders close to the drumlins, and medium or fine sand in a down drift direction. Such beaches are relatively uncommon and are found mostly east of Cape LaHave.

Most of the large beach systems of the South Shore have little or no active supply of sediment from drumlins, and consist of fine to very fine sand with small quantities of local bedrock pebbles. They are often backed by dunes which are frequently eroded by washover (e.g. Crescent and Cadden beaches described by Bowen et al., 1976). On some beaches (e.g. Kingsburg and Summerville) there are several parallel dune ridges suggesting beach progradation.

Seasonal profile changes (Fig. 64) and sediment budgets of two contrasting beaches southwest of Lunenburg (Fig. 62) were studied in detail by Urquhart (1976).

1. Kingsburg beach, in Kings Bay, is approximately 650 m long and backed by broad dunes and two small ponds. The sediment is a well sorted fine sand, which extends seaward in the lee of Point Enrage as far as the 10 m isobath. Beyond this, bedrock and gravels occur. Very low eroding drumlins occur at either end of the beach, and supply an estimated 20 m^3 of sand per year to the beach. This is insignificant compared with an estimated annual movement of 23 000 m^3 offshore in winter and back onto the beach in summer (Fig. 64). The sediment on the beach was presumably derived from vigorous drumlin erosion when sea level was 20 or 30 m lower, and has transgressed landwards as sea level rose.
2. Hirtles Beach in Hartling Bay is 1.6 km long, and is backed by four high eroding drumlins separated by lagoons. The western part of the beach is cobble gravel, with sand increasing towards the central part of the beach. The eastern beach is largely a boulder armour overlying till. The two easterly drumlins are retreating more than 1 m per year. Annual sediment supply is estimated to be 500 m^3 of gravel and coarser material and 2500 m^3 of sand. About 70 000 m^3 of sand moves onto the beach in summer, and offshore again in winter (Fig. 64).

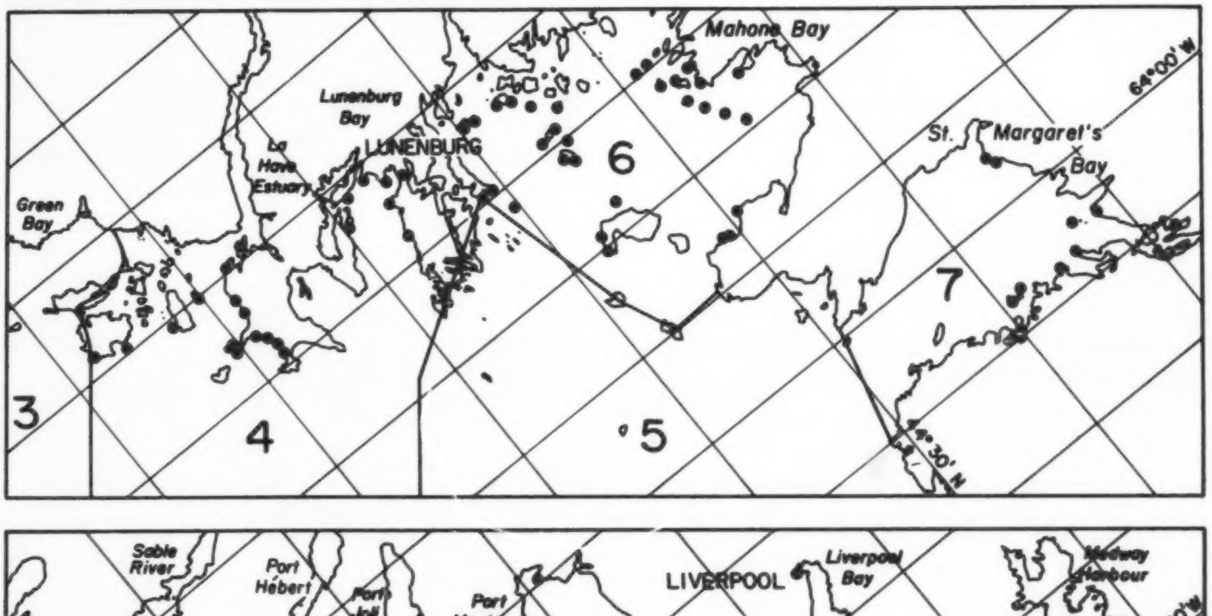


Figure 63. Coastal sectors I to 7 used for sediment budget analysis, and the location of eroding cliffs (dots).

Marsh and tidal flat

Very small areas of poorly developed tidal flat and marsh occur at Summerville, in LaHave estuary, in sheltered inlets on the west side of Lunenburg Bay, and at the head of St. Margaret's Bay.

HOLOCENE SEDIMENT BUDGET

Introduction

In this section, a sediment budget is drawn up for Holocene sediments of the South Shore. First, modern rates of sediment supply and export from the coastal zone landward of the 'sand line' are determined, and where possible compared with observed sedimentation rates. These data are then extended to the last 10 000 years, by comparing total sediment accumulation since that time with total estimated sources.

Sources of sediment

Drumlin erosion is the principal source of sediment to the South Shore at the present time (Piper and Keen, 1976; Piper, 1980). Although several large rivers (Gold, LaHave, Medway, Mersey) drain to the South Shore, they drain areas with thin soil cover, have rather low gradients, and most of their bed load is trapped in talweg irregularities before it reaches the sea. Only in southwestern Nova Scotia do sandy outwash soils become thicker (e.g. in the Sable River valley). As an example of the low terrigenous sediment input, muds in the Gold River estuary in Mahone Bay are highly diatomaceous in contrast to those closer to eroding till cliffs. The average denudation rate of mainland Nova Scotia, based on sediment load of rivers, is at present approximately 6.7 mm/ka (Piper and Keen, 1976, p.8) and prior to European settlement would have been lower (Scott, 1980).

Letson (1980) suggested that submarine erosion of till may take place on shoals, but that the amount of sediment supplied in this way is small. Tidal current erosion of mid- to early Holocene sediments may be important locally in southern Mahone Bay, but regionally this is not a significant sediment source. Attrition of coarse sediment is of minor significance.

Sediment budget model

Figure 65 summarizes the sediment budget model used in this study. Erosion of till cliffs supplies sand, silt, and clay to the nearshore zone and leaves a residual lag of boulders. In addition, transgression of nearshore sediment with rising sea level is an important source of sand (Piper, 1980) leaving lag gravel and boulders offshore beyond the 'sand line'. There is no evidence of longshore transport of sand from one coastal sector to another within the coastal zone. Beaches (sand) and

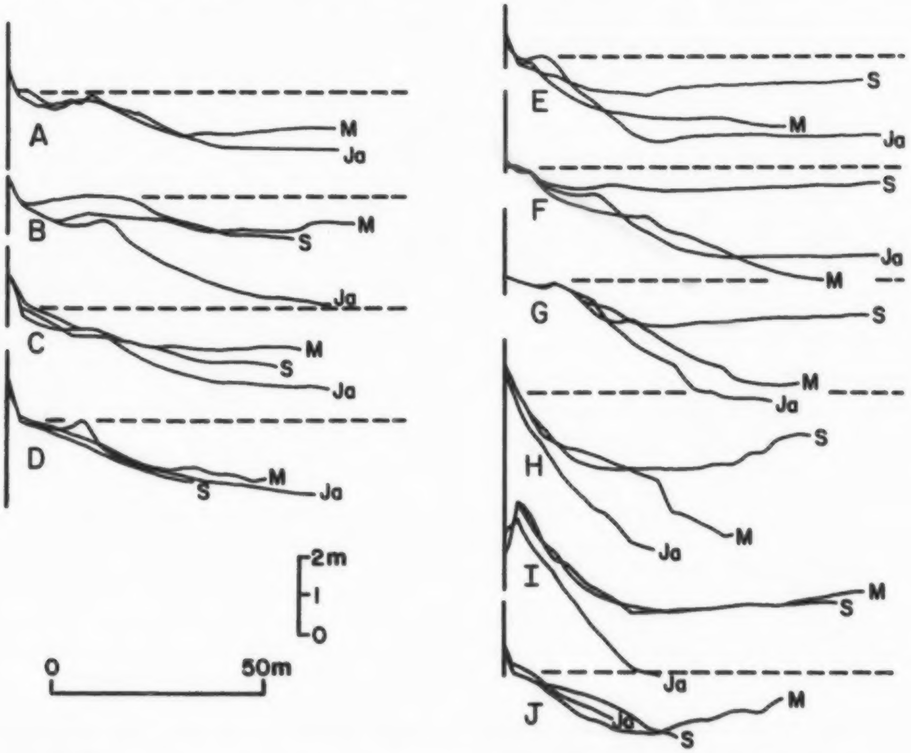


Figure 64. Beach profiles for Kingsburg (A-D) and Hirtles (E-J) beaches, southwest of Lunenburg. Locations shown in Figure 62; beach profiles are for May (M) and September (S) 1976, and January (Ja) 1977. Dashed line is MHWM.

lagoons (mostly silt and clay; sand in some) on the South Shore represent a relatively minor sediment sink that maintain an approximately constant volume through time, since they are constantly re-eroded during transgression. Large prograded beach systems of the type found at Lawrencetown or Pomquet (Bowen, 1976) are not present in the study area. Only clay is transported in suspension to the continental shelf in significant quantities.

Contemporary rates of sediment supply

The coastline of the South Shore has been divided into 7 sectors (Fig. 63); in each sector the surface area of eroding drumlins has been estimated from field and air photo investigations. Average retreat rates have been estimated, based on the data in Table 6. Hence for each sector, the contemporary sediment supply rate for eroding coastal drumlins (which approximates the total sediment supply rate) has been estimated (Table 7).Errors in determining surface area are estimated at 20% and in erosion rate at 40%. The amount of different grain sizes supplied can be estimated from our till grain-size analyses and those of Nielsen (1976).

These data show that the greatest amount of sediment supply at the present time occurs in the area from LaHave estuary to Mahone Bay, and least in the rocky coastal areas between Port Mouton and Lockeport, between Port Medway and Cape LaHave, and around the Aspotogan Peninsula and the islands off St. Margaret's and Mahone bays.

Export of clay from the coastal zone

Letson (1980) made a detailed analysis of grain size modes in small basins in western Mahone Bay adjacent to eroding till cliffs. Basinal sediments showed a similar grain size distribution to the silt and clay fraction of tills (Fig. 66), but with a 25% clay deficiency. The silt to clay ratio in the central basin of Mahone Bay is little different; the missing clay is estimated to be 4000 m^3/a, suggesting a clay export of around 1000 m^3/a. Mudie (1980, Fig. 5.11) calculated a pollen budget for surficial sediments of Mahone Bay and estimated that about half the annual pollen influx to Mahone Bay was ultimately transported to the open shelf. The hydrodynamic equivalence of clay flocs and pollen is variable but these figures are consistent with the clay export estimates.

An analogous calculation comparing clay content of tills and muds in St. Margaret's Bay gives similar results. In the Lunenburg to LaHave area, where mud accumulation is rare except in LaHave estuary, a higher proportion of clay must be removed. Southwest of Cape LaHave, most drumlins contain less than 5% clay, but commonly 15-25% silt. Little of this sediment is seen in the coastal zone. Supply rates are too low to make accurate budget calculations.

There are no significant coastal or inner shelf sinks for this clay other than in the nearshore basins: salt marsh is very rare, and little mud is trapped in estuaries except the LaHave.

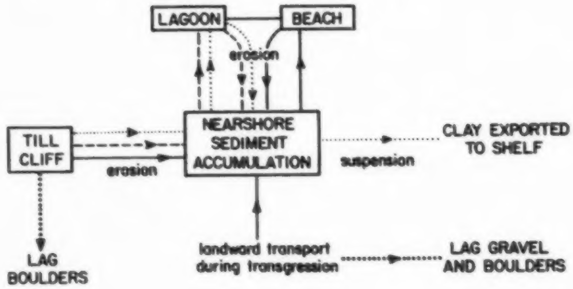


Figure 65. Sediment budget model. For explanation see text. Heavy dots: gravel; lines: sand; dashed lines: silt; light dots: clay.

Table 7. Nearshore sediment budget.

Sector	Area of drumlin face (1) $m^2 \times 10^4$	Retreat rate (2) m/a	Till (3) % sand	% mud	Annual volume (4) sand $m^3 \times 10^2$	mud	Inferred area of eroded till $m^2 \times 10^6$	Volume supplied if till 6 m ave. height $m^3 \times 10^6$ Sand	Mud	Nearshore sediment volume (5) $m^3 \times 10^6$ Sand	Mud	Beach & dune vol. $m^3 \times 10^6$
1	1.0	1	35	15	35	15	? 1	2	1	90	3	15
2	2.5	1	30	25	75	63	?20	40	35	300	15	15
3	0.1	1	40	30	4	3	? 5	12	9	80	0	6
4	20	0.5	35	45	350	450	30	60	75	150+20(6)	<120(7)	5
5	0.1	1	35	15	4	2	? 5	10	4	170	0	<0.5
6	20	0.25	35	55	175	275	10	20	30	16+10	90	1.5
7	2.5	0.25	35	25	22	16	5	10	8	4+10	100	0.5

(1) determined from air photographs augmented by field observations;

(2) average based on Table 6;

(3) based on Nielsen (1976) and our own data, particularly Letson (1980) for sector 6 and Urquhart (1976) for sector 4;

(4) Assuming constant erosion rate, this equals total Holocene supply in $m^3 \times 10^6$ (except for Mahone Bay);

(5) to the 50 m isobath, based on figures 19, 30, 67, 68, 69;

(6) sand in mud;

(7) depends on thickness of mud in LaHave estuary; asssume 10 m.

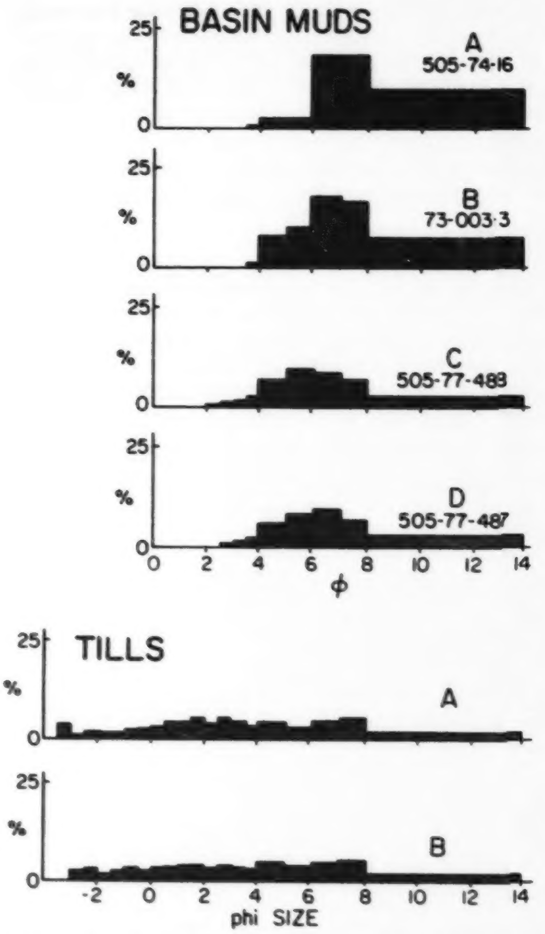


Figure 66. Grain size distribution of till and basinal mud samples from southwest Mahone Bay, showing deficit of clay in basinal mud. For explanation, see text.

Thus the clay that is removed must accumulate either in mid-shelf basins (such as Emerald Basin) or in more distant sites. The total clay export from the study area is estimated at 4000 m^3/a.

Thickness of contemporary sediments

The extent and thickness of the late Holocene Sable Island Sand and Gravel of acoustic unit d2 is more difficult to map in those areas for which only 3.5 kHz profiles are available (i.e. southwest of Cape LaHave), since the sandy lithofacies is in places difficult to distinguish from stratified early Holocene unit c (Fig. 67). East of Cape LaHave, where more sparker profiles are available, the thickness of unit d2 is more certain (Fig. 68).

The Sable Island Sand and Gravel occurs in basins within 5 km of shore in water depths between 20 and 50 m. Typically it is less than 15 m thick, but locally fills deep channels and depressions up to 25 m thick. Piston cores in acoustic unit d generally penetrate 1-3 m of sand resting on older material (Fig. 69). No cores have been obtained from very thick accumulations but drillholes by Ocean Science and Engineering Inc. (Libby, 1969) off the Ovens, Lunenburg Bay, penetrated 7 m of sand and gravelly sand. The character of deeper sediment elsewhere is inferred to be similar. Using 1978 data, Piper (1980) calculated the sediment volume in the major basins of acoustic unit d2, assuming an average thickness of 2 m. This is a very conservative assumption for most basins; revised estimates of nearshore sediment volume are presented in Table 7.

The thickness of the LaHave Clay facies of acoustic unit d1 is much more difficult to determine, because of the presence of a subbottom acoustic mask, which Kepkay (1977) has shown to be gas bubbles in the upper 2 m of the mud. In the central basin of St. Margaret's Bay, however, the acoustic mask dips down at the basin margin to reveal sediment at least 7 m thick. Lower resolution sparker seismic reflection profiles (Piper and Keen, 1976) suggest a total thickness of 10-15 m. The other major development of LaHave Clay, in Mahone Bay, appears to be 6-12 m thick from sparker profiles. Minor occurrences of LaHave Clay in Liverpool Bay and Port Mouton are included in Figure 67. Total volume estimates are shown in Table 7.

Rates of sedimentation

Rates of sedimentation can be calculated from sediment accumulation above datable horizons; the most important of these are:

(i) ^{14}C dated horizons (Table 1), discussed above,
(ii) the ragweed pollen horizon marking European land settlement and clearance (Mudie, 1976, p. 61, 1980, Fig. 5.9). Data are available for Mahone and St. Margaret's bays.
(iii) estimated ages based on palynological assemblages (Mudie, 1980).

Figure 70 presents the rate of sedimentation of LaHave Clay. The rates are 2 mm/a in basins fed directly by eroding drumlins and 0.5-1.0 mm/a in basins lacking adjacent till cliffs. Sable Island Sand and Gravel accumulation rates are very variable. Available cores are concentrated in areas of reduced sand sedimentation, but in thick sand sections rates must reach several millimetres per year.

Total Holocene sediment supply

Total sediment supply from drumlin erosion in the last 10 000 years can be crudely estimated in two different ways. One way is to assume that the present sediment supply rates have remained constant over the last 10 000 years, implying a similar abundance of drumlins at the coastline in the past, when sea level was lower and the coastline was south of its present position. The other way is to estimate the total volume of drumlins removed by coastal erosion in the last 10 000 years from the distribution of planed-off till platform, assuming an average drumlin height. This method can be used only if drumlins have not been completely eroded during transgression.

Relative sea level was at approximately −30 m about 10 000 years ago. The volume of eroded drumlins can be estimated from the areal distribution of planed-off till (Fig. 48) in St. Margaret's Bay (sector 7, Fig. 63), Mahone Bay (sector 6) and Lunenburg Bay to LaHave estuary (4). However, to the southwest (sectors 1-3), and offshore from St. Margaret's and Mahone bays (sector 5) there is little till preserved in water depths of less than 40 m (Fig. 31); if originally present, it must have been removed through erosion. Till is abundant farther offshore, particularly between Liverpool Bay and LaHave estuary, suggesting that nearshore till may also have been common in these areas. The areas given in Table 7 are thus assumptions, based on abundance of till on land and farther offshore. In Table 7, sediment volumes have been calculated assuming the till was 6 m thick and of grain size distribution similar to that sampled on land.

Interpretation of Holocene sediment budgets

The observed Holocene sand accumulation in St. Margaret's and Mahone bays (sectors 7 and 6) and the LaHave-Lunenburg area (sector 4) is approximately balanced by the estimated supply by till cliff erosion in the last 10 000 years for St. Margaret's Bay, and in the last 5000 years (since breaching of the sill) in Mahone Bay. Mud supply from till may be insufficient, suggesting some derivation from erosion of acoustic unit c. Elsewhere, observed quantities of sand greatly exceed predicted supply by till erosion over the last 10 000 years, and cannot be accounted for solely by assuming that the offshore till was more extensive. Rather, the excess sand must have been derived from glacial outwash at the late Wisconsinan ice margin (probably more important in the west of the region), or by late Wisconsinan erosion of mid-Wisconsinan tills. The sand has then been largely trapped within the coastal zone, and has moved landwards during the Holocene transgression.

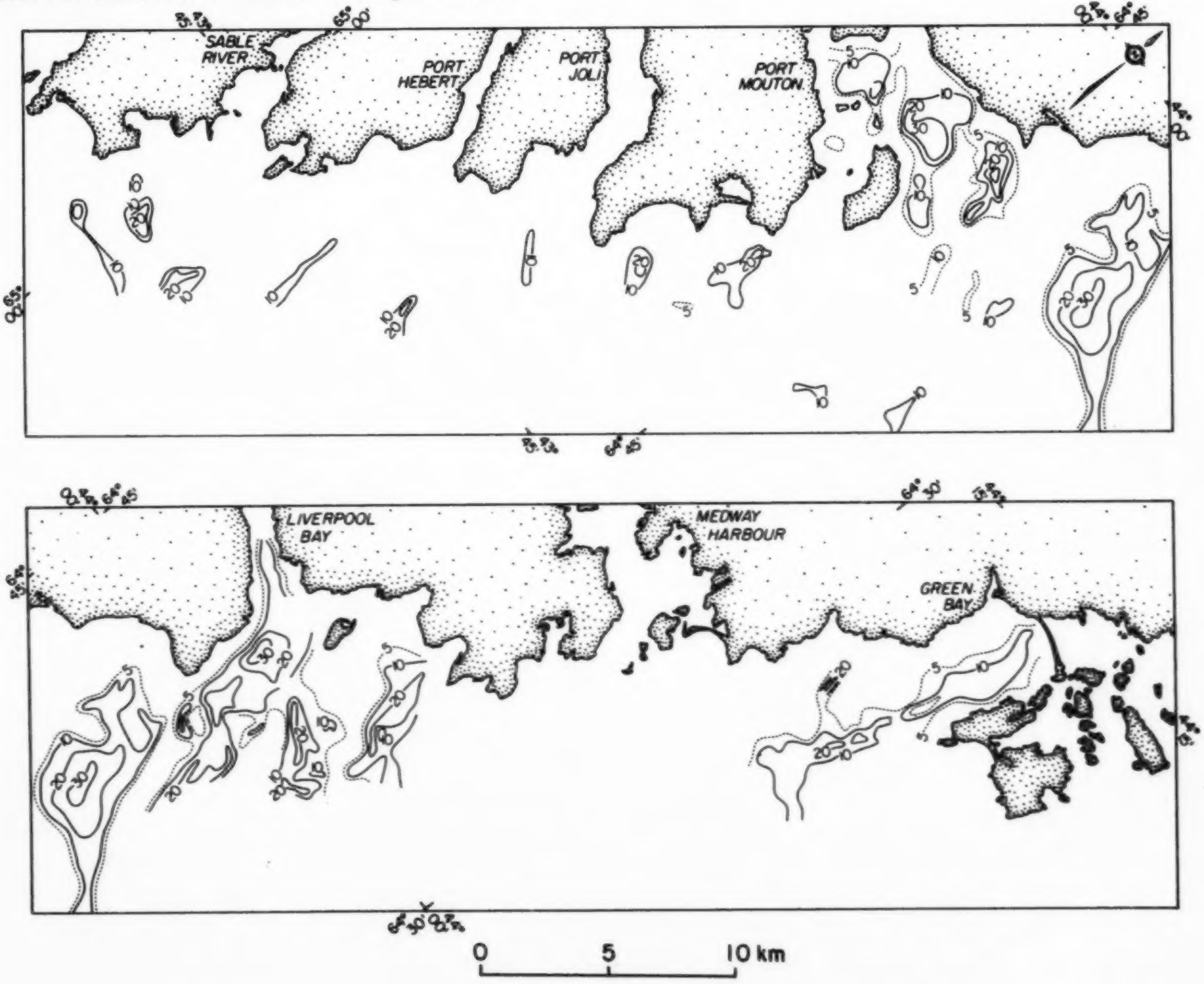


Figure 67. Isopach map (milliseconds two-way travel time) of surficial sediments in acoustic units c and d, west of Cape LaHave. Zero contour line is limit of sediment mapped in Figure 48.

GEOMORPHIC EVOLUTION

The earliest stages of geomorphic evolution of the South Shore are uncertain. Goldthwait (1924) suggested that parts of Nova Scotia might represent an exhumed pre-Carboniferous surface. According to Barnes (1976), the very thin Carboniferous outliers in St. Margaret's and Mahone bays suggest that the present landscape is close to the sub-Carboniferous surface.

The principal first-order physiographic feature in the Maritime provinces is the tilted peneplain which descends from 600 m above sea level in northern Cape Breton to intersect with sea level along the Atlantic coast of Nova Scotia, producing the overall straight trend of the coastline (Goldthwait, 1924). This peneplain has been generally regarded as mid-Cretaceous in age (King, 1972) although Cooke (personal communication, 1980), by comparing offshore sediment thickness against post-peneplain erosion, has suggested that it is probably Miocene. Occasional outliers of Cretaceous clay in low-lying areas in central Nova Scotia suggest this peneplain originally had considerable relief.

Nova Scotia has probably experienced intermittent glaciation since the Pliocene (Piper, 1975). Minor glacial advances onto the South Shore area probably developed about a South Mountain ice cap (Grant, 1977) but more extensive glaciations saw a coalescing of Maritime centres and southward flow of ice across Nova Scotia from New Brunswick (Nielsen, 1976; Wightman and Cooke, 1978; Grant and King, 1984). Thus the South Shore must have experienced multiple glacial erosion events, but with only a few basic erosion patterns. The age of the glacial erosion features along the South Shore is thus unknown, but most of the erosion appears to be pre-Wisconsinan.

The most prominent glacial erosion features are deep basins, often silled. The deepest are almost all developed on granite: northeast Mahone Bay, St. Margaret's Bay, and the Mouton Bay-Liverpool Bay area (where the edge of the batholith marks the coastline). However, granite also forms resistant peninsulas at Aspotogan and Peggy's Cove; in the former case the metamorphic aureole in Meguma rocks appears to be the most resistant lithology. Granite erosion is promoted by the widely spaced joint pattern. It is not clear whether a particular spacing or orientation of joints results in particularly favourable conditions for erosion.

Basin erosion is also more pronounced in the eastern part of the study area compared with the western, resulting in a much more indented coastline. This corresponds approximately to the area of the Lunenburg drumlin field, and may represent a major southward flowing ice stream confined on the west by North Mountain and Cape Blomidon (Grant, 1963).

Most of the major depressions transverse to the coastline are oriented south-southeast: for example, Halifax Inlet, St. Margaret's Bay, Lunenburg Bay, Liverpool Bay, Gull Bay and Port Joli. This direction is slightly oblique to both the regional dip of the Meguma and the dip-slope of the Miocene peneplane. Fyson (1966) suggested that a major set of high

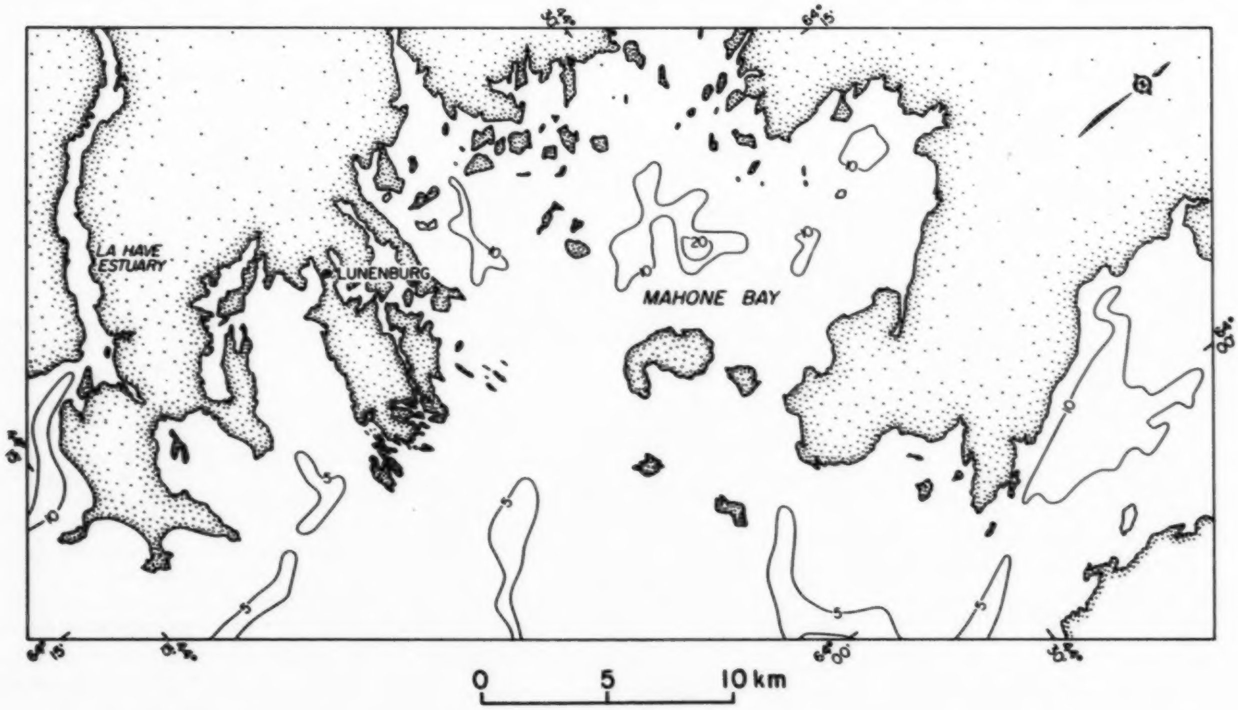


Figure 68. Isopach map (milliseconds two-way travel time) of surficial sediments of acoustic unit d only, east of Cape LaHave. Zero contour line is limit of sediment mapped in Figure 48.

angle faults and associated fractures controlled this geomorphologicallineament. Such faults and fractures cannot be easily mapped on land, but have been mapped from magnetic anomaly patterns in Mahone Bay and Lunenburg Bay. They appear to cut both Meguma and granite bedrock.

In several of these transverse depressions, the southwest margin is steep whereas the slope to the north or northeast is more gentle. Examples are St. Margaret's Bay, Liverpool Bay, and Halifax Inlet.

The strike of the Meguma is transverse to the southward flow of ice. The south-dipping flanks of anticlines form resistant ridges, as clearly seen in Lunenburg Bay (Ovens Point, Rose Point: Fig. 13). Jointed north-dipping limbs are more easily quarried (Goldthwait, 1924). No explanation has been found for the location of the marked sill in St. Margaret's Bay within the area of granite bedrock several kilometres north of the granite-Meguma contact.

The transverse depressions extend inland as major valleys, but can mostly be traced seaward only about as far as the 60 m isobath. The large valleys may mark the site of preglacial rivers, but the close spacing of smaller valleys west of Liverpool suggests not all valleys are preglacial. The transverse depressions could be the result of structurally controlled glacial erosion; alternatively, the location of depressions may be controlled by the spacing of sub-ice drainage channels that produced rinnentaler. The inter-relationship of rinnentaler and transverse depressions and basins has been discussed above.

Seaward of the 60 m isobath, physiography is irregular (Fig. 3, 5). There are few linear trends either transverse or parallel to the coastline.This irregularity appears to be a feature of the bedrock surface, and in the east part of the region rinnentaler are the predominant morphological feature (Fig. 22). The change in seabed morphology landwards probably reflects a change in style of glacial erosion. In much of the area between LaHave River and eastern St. Margaret's Bay, the bedrock surface on land is completely masked by thick drumlinoid till that reaches thicknesses of over 60 m (from well records), and has been modified little by subaerial

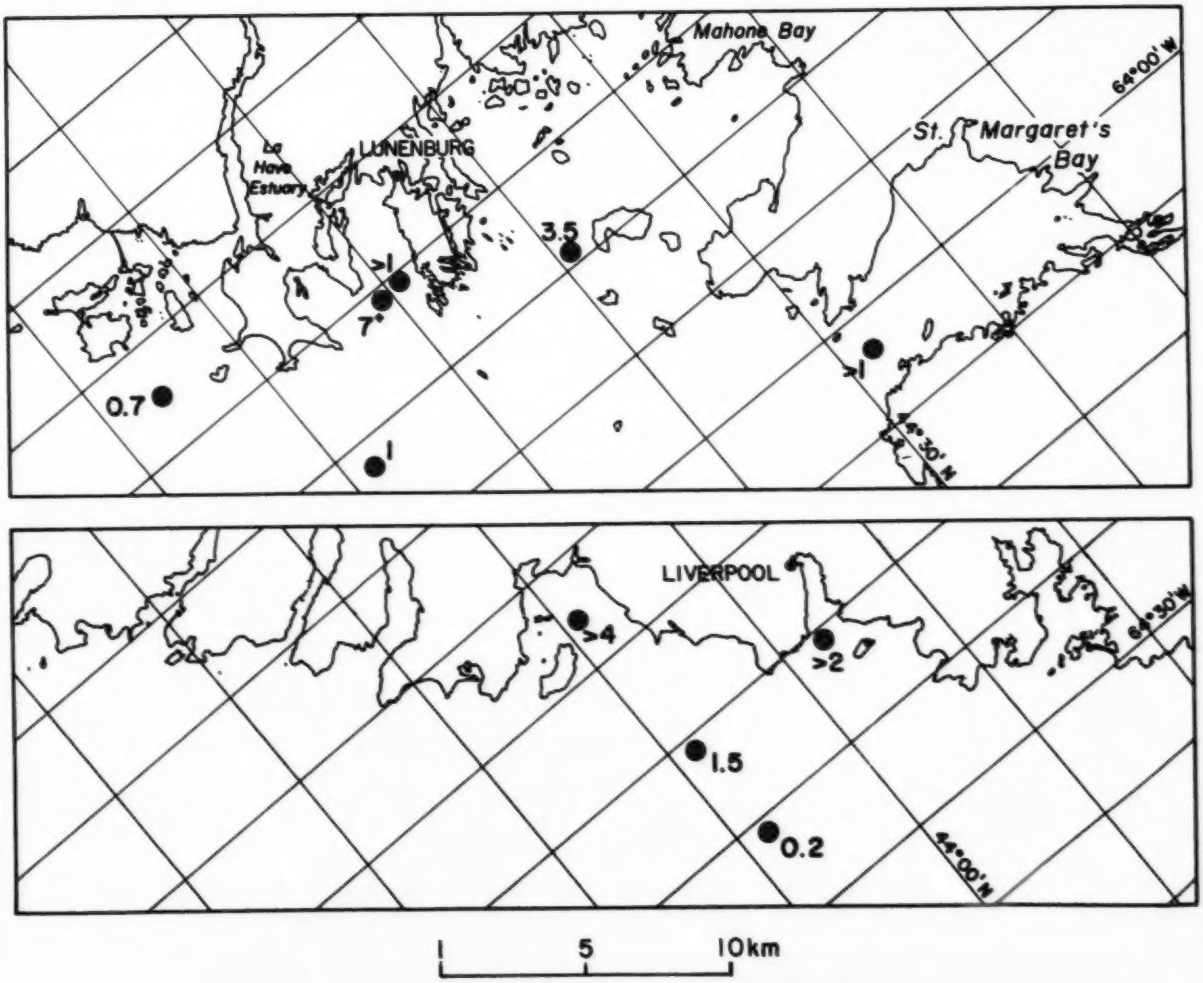


Figure 69. Thicknesses cored in acoustic unit d2 (in metres)

processes. Elsewhere on land in the South Shore region, till is only of minor morphological significance, forming a thin rubbly sheet, with rare drumlinoids.

At sea, the earliest modification of the till surface is attributable to local meltwater dissection, forming rinnentaler. These sub-ice channels clearly have a complex history, since in places they cut bedrock and are filled with till. They must have been repeatedly flushed and then filled with sediment in successive glaciations. In any glaciation extensive enough for ice to move southwards across the Minas Basin and South Mountain, stagnation would occur on the South Shore during the retreat phase as a result of marine incursion in the upper Bay of Fundy, thus setting up conditions for extensive sub-ice drainage.

However, the principal modification of till offshore took place by wave erosion in the coastal zone during the late Wisconsinan sea level lowering to –120 m and the subsequent transgression. Probably 95% of the original till was eroded, leaving only a discontinuous veneer, except where till is preserved beneath younger sediments in depressions.

Coarse fluvioglacial sediment is of morphological significance only within nearshore rinnentaler, many of which have thick gravel sequences. Thick muds of acoustic unit c, however, fill bedrock depressions over wide areas. In St. Margaret's Bay and Mahone Bay, sediment is ponded approximately to the maximum depth of the channel cutting the sill. Elsewhere (e.g. Port Mouton, Lunenburg Bay) it is not clear whether the widespread flat or gently sloping upper surface of the early Holocene sediments (Fig. 19) is depositional or erosional.

Changing postglacial relative sea-level has played a major geomorphological role. The late Pleistocene unconformity between acoustic units b and c is widespread in water depths ranging from –120 m offshore to –60 m within a few kilometres of the coastline. In most areas it is overlain by sediments of acoustic unit c. In contrast, planation surfaces in water depths of less than 50 m truncate acoustic unit c, and thus appear to be Holocene in age. Microfossils in facies 2 suggest rising sea level may have been responsible for ice retreat. The channel systems just north of Bull Rock in Mahone Bay (Barnes and Piper, 1978) and in Lunenburg Bay (Fig. 7) appear to have developed subaerially after deglaciation while sea level was low.

Slowly rising sea level over the last 10 000 years has resulted in the overall form of the coastline being that of submergence, with drowned valleys and mid-bay barrier beaches. Silled basins that were formerly lakes have been

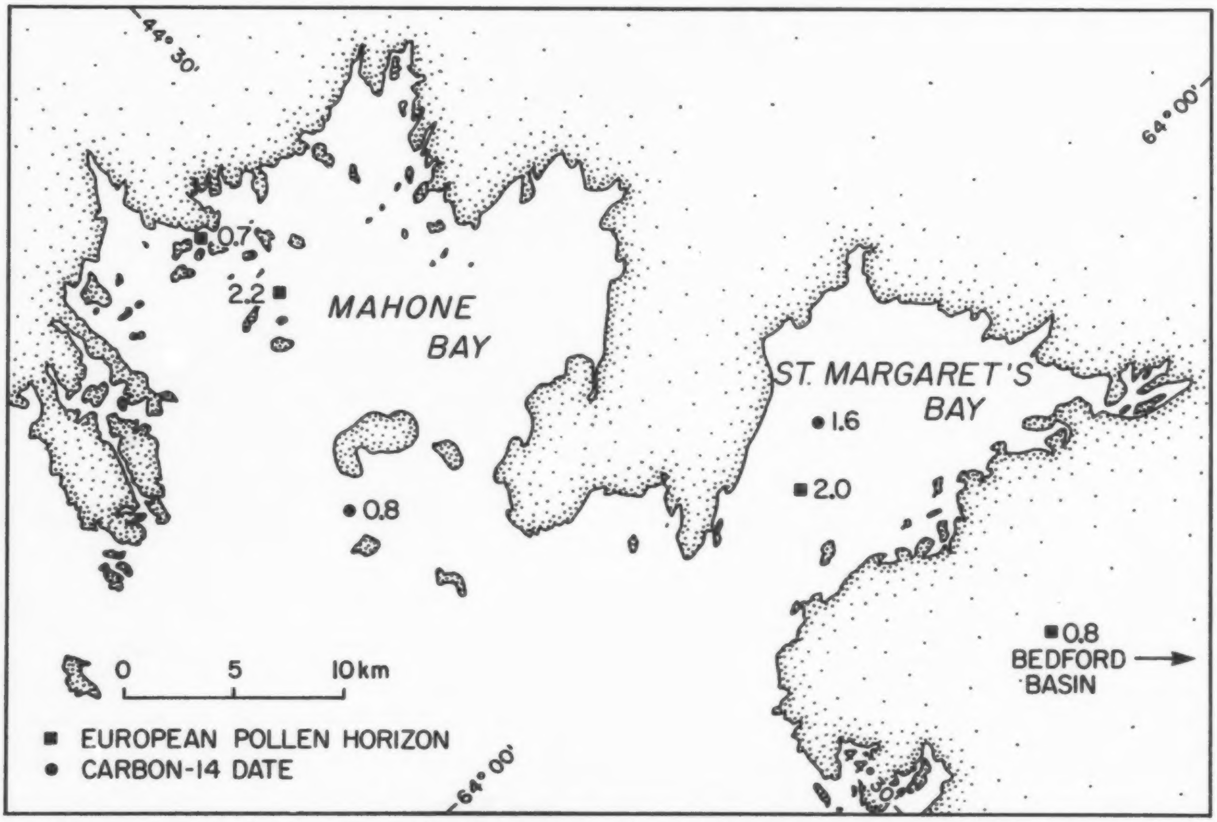


Figure 70. Rates of sedimentation of LaHave Clay (acoustic unit d1) in millimetres per year, based on ^{14}C dates or recognition of European pollen horizon.

invaded by the sea (Barnes and Piper, 1978). As sea level has risen, successively higher drumlins have been subjected to wave erosion, yielding a continual supply of sediment to the coastal zone.

The morphology of the sea floor controls the location and intensity of wave erosion as sea level rises. Mahone Bay has a shallow bedrock sill at –14 m that was breached by rising sea level about 4500 BP, but only when the sea reached about –10 m was there sufficient exposure to open ocean waves for rapid erosion of till to take place (Fig. 8). As a consequence, there is a widespread shallow terrace in Mahone Bay at 0-10 m water depth, which then drops off steeply until the ponded basin floor at around 29 m is reached. There is a similar effect in St. Margaret's Bay, where although the maximum sill depth is 58 m, the entrance to the bay would have been very narrow until the sea reached approximately –25 m (Fig. 8). In contrast, Lunenburg Bay is not silled, and has no prominent terrace, except in 0-2 m water depth (the origin of which is unclear).

In addition, wave destruction of drumlins exposes drumlins farther landward to wave attack, especially as sea level rises to submerge the planed-off shoal. This is very clearly seen in Mahone Bay, where flat-topped till shoals record former positions of sea level at the time drumlin erosion took place (Fig. 71). Small shoals in water depths of 17-19 m are common, and were probably planed off by a lake or lagoon at this level before marine incursion across the outer sill. In the exposed areas southeast of Rafuse Island, shoals lie in 7-15 m of water. The destruction of these drumlins led to erosion of drumlins at 3-6 m below present sea level around Rafuse Island, and the removal of this protection permitted the present rapid erosion around Rous Island.

CONCLUSIONS

Bedrock distribution

The known distribution of the Meguma Group rocks and Devonian granites has been extended 5-10 km offshore. The geomorphology of the offshore is influenced by bedrock geology in that overdeepened basins commonly occur in granitic terrane.

Late Pleistocene glacial history and sediment distribution

Many of the interpretations of late Pleistocene glacial history complement those of L.H. King and G.B. Fader (personal communication, 1983) on the main part of the Scotian Shelf. They considered Wisconsinan sediment depo-

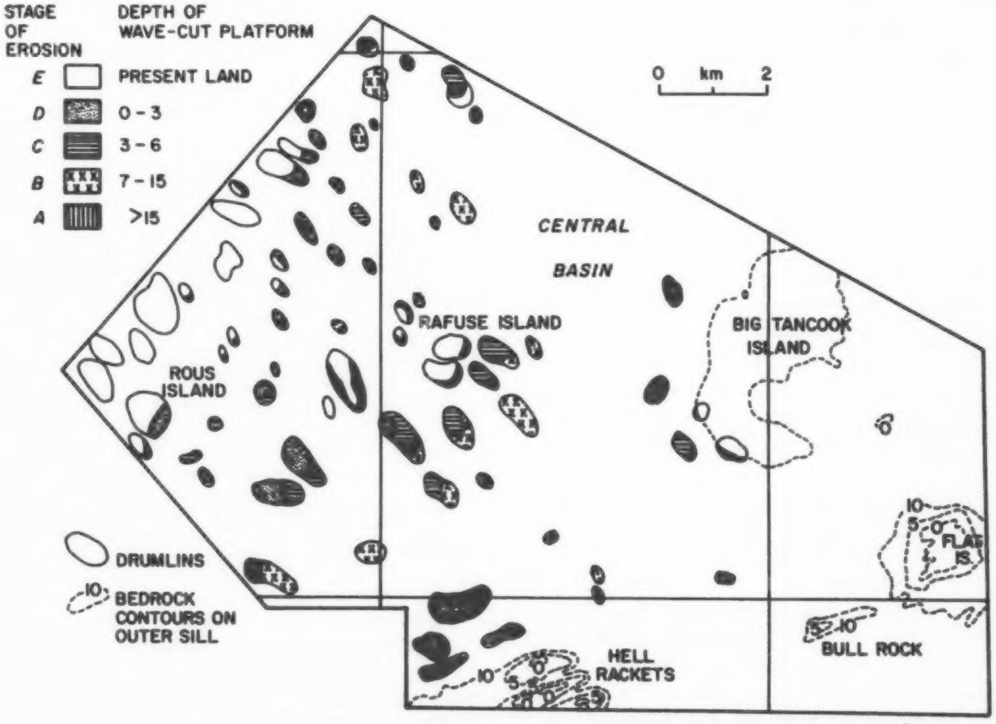


Figure 71. Drumlins in southwestern Mahone Bay, showing depths of wave- cut platforms interpreted in terms of progressive erosion of exposed drumlins with rising sea level. Four stages of erosion (A to D) corresponding to four depth ranges are recognized. A represents drumlins completely planed off at a depth of 18 to 19 m, prior to marine incursion. B is erosion from the time of marine incursion to about 3000 years, C from 3000 years to 1500 years, and D erosion in the last 1500 years.

sition on the Scotian Shelf to be essentially the result of almost continuous glacial retreat. A similar pattern has occurred along the South Shore. Till is overlain by a draped transparent acoustic unit, perhaps the result of sedimentation from beneath floating ice. This was followed by thick stratified sediment, apparently sandy or gravelly glacial outwash. A major unconformity that truncates the transparent acoustic unit and stratified sediment represents a lowering of sea level to –120 m, and is overlain by stratified sediments which laterally interfinger with till close to the present coastline. This till is believed to mark the late Wisconsinan ice maximum, which appears to have been of very limited extent in Nova Scotia.

The till and outwash are overlain by a veneer of muddy sediment representing rapid sedimentation during late Wisconsinan ice retreat. This sequence appears to be transgressive, suggesting sea level rose as the late Wisconsinan ice retreated.

Later Holocene and contemporary processes

Abundant nearshore deposits of sand and gravel are partly supplied by coastal erosion of till cliffs, but much must have migrated landwards with the Holocene transgression from a coastal reservoir of coarse late-glacial outwash material. The close correlation between heavy mineral assemblages in nearshore sediment and till suggests longshore movement of sand is minor. The seaward limit of sorted sands marks the transition from predominantly onshore-offshore sediment transport of the nearshore zone to the more powerful longshore transport of the inner shelf.

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